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GENERAL MOTORS CORPORATION

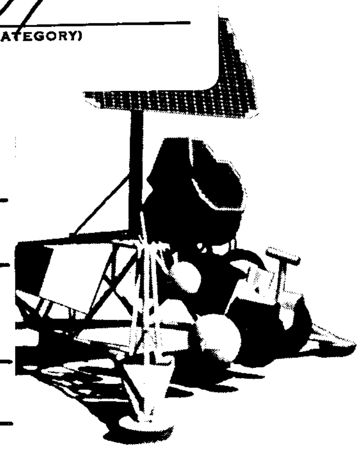
Final Report

SURVEYOR LUNAR ROVING VEHICLE

Phase I — JPL Contract 950657

VOL. II: APPENDIXES

Section IV Reliability



GM DEFENSE RESEARCH LABORATORIES SANTA BARBARA, CALIFORNIA

TR64-26

April 23, 1964

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Section IV Reliability

GM DEFENSE RESEARCH LABORATORIES SANTA BARBARA, CALIFORNIA

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PREFACE

This report is one of a series of reports prepared under JPL Contract No. 950657 by GM Defense Research Laboratories, Santa Barbara, California, and its major subcontractor for electronics, Radio Corporation of America, Astro-Electronics Division, Princeton, New Jersey, under N.A.S 7.100.

SECTION IV

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APPENDIX I

RELIABILITY TRADEOFF STUDIES

A. GENERAL

The primary reliability activity of the Phase I SLRV program in its early months was to support the systems configuration and mission analysis efforts in the selection of a preferred vehicle system concept. This was accomplished by providing comparative reliability data on the competing concepts, in a form that could be incorporated into the overall tradeoff studies.

With a mission as complex as the SLRV, a simple comparison of the reliabilities of the competing configurations as a function of time is not adequate. In fact, as will be shown later, it can be erroneous. The only criteria which allows consideration of all factors, is to compare the probability of achieving the mission task for each of the competing concepts.

The remaining paragraphs of this appendix describe trade-off studies performed in the first few months of Phase I.

B. APPROACH

The mission characteristics of the SLRV suggest consideration of two modeling concepts to wit: a functional sequence model, and a time profile model. The functional sequence model would be the simpler and less complicated. However, functional operational sequences were not yet defined, being one of the variables under study. As an example, we did not yet know the number of TV survey pictures to be taken at each survey stop, since the TV angle coverage was yet to be defined.

The time profile model tends to be more cumbersome, but it provides the multiple degrees of freedom needed when there are many variables under study. It also lends itself easily to computer programming. The time profile model was chosen for Phase I reliability analysis studies.

The equipments visualized for the SLRV consisted of electronic, electromechanical, and mechanical types for which the failure distribution appeared to be best described by the classical exponential distribution. The most likely suspect for deviation from the exponential distribution would be wear-out phenomenon of the mechanical assemblies. A cursory review of the anticipated design stresses and total required mission operating life including earth checkout, indicated that the design life of the mechanical assemblies could probably be pushed out far enough to safely assume mission operation in the constant failure rate area.

Since the time profile model had been chosen, all failure criteria was expressed in terms of time. This has necessitated use of an "equivalent time" concept on some cyclic events. This concept assigns a failure rate per unit of time which contributes equally to the probability failure.

Failures in equipments while they are in a non-operating or non-energized condition had not been considered thus far in the analysis effort. While the existance of such failures was recognized, the effect was considered to be rather small. The ratio of operating to non-operating failure rates used on other programs has ranged from 50:1 to 500:1. If these values are valid, the error introduced in the SLRV analysis from this source was probably less than 1% in total failure rate. The effect of non-operating failures remained to be investigated and appropriately factored into future studies.

C. EQUIPMENT

The prediction of mission reliability performance required the identification and mechanization of tentative subsystems of the SLRV. The subsystems configuration chosen represented a best judgment of how the subsystem performance requirements might be fulfilled. These subsystem configurations were continually being updated as new information became available. The mission reliability performance studies used systems made up of combinations of the following subsystems:

Communications

S-Band – The S-Band communications subsystem is a phase locked direct vehicle-earth link. The transmitter is all solid state in the low power mode and adds a non-solid state power amplifier in the high power mode. The low power mode is a fraction of a watt with a bandwidth of several hundred cycles into omni-antennas. The high power mode is in the 1 to 10 watt range into a high gain antenna and has a 20 KC bandwidth. The power amplifier used in the model is an amplitron. It was probable that the amplitron will be replaced with a triode in future models. The receiver is an all solid state design.

VHF Vehicle – The VHF communications subsystem is a phase locked vehicle-Surveyor link, which relays all data through the Surveyor Basic Bus-earth link. The vehicle transmitter is all solid state with a high power mode of 1-3 watts at 220 KC bandwidth and a low power mode of a fraction of a watt at a 2 KC bandwidth. The antenna system is omni-directional. The receiver is all solid state.

VHF Basic Bus – Use of the VHF link to the basic bus requires a VHF transmitter-receiver combination similar to that on the vehicle. A small amount of interface electronics to the basic bus is also included.

Telemetry

The telemetry model is an all solid state PCM subsystem of approximately 70 analog channels and 200 discretes. In addition, two subcarrier oscillators are included for the DIBSI experiment. The telemetry sensors or data sources have not been included in the model.

Command and Control

The vehicle command and control is an all solid state subsystem containing approximately 100 commands. Subsystems compatible and non-compatible with Surveyor format were modeled, with no significant difference in reliability from an equipment point of view. The subsystem contains six vehicle subsystem decoders with solid state power switching.

TV

The TV subsystem modeled is all solid state except the vidicon. The vidicon is externally mast mounted away from most of the electronics. The TV head has a 360° azimuth capability. Two systems were modeled, a 600 x 600 line system requiring a 220 KC bandwidth, and a 200 x 200 line system utilizing a 20 KC bandwidth. The predicted vidicon failure rate is one of low confidence, representing essentially engineering judgment.

Power Subsystem

Solar Cell – The solar cell power subsystem consists of a solar array, variable attitude positioner, secondary battery and power management electronics. The solar array is made up of series-parallel cell strings with diode isolation, and cell protective covers. The model was patterned after the Relay satellite panel. A degree of uncertainty exists in the area of solar cell susceptibility to solar flares. The battery used in the model is a nickel cadmium series-cell unit. Silver cadmium is currently being reviewed. Power capabilities of the system vary from 80 to 120 watt-hours of storage capability and from two to four square feet of solar panel.

Radiosotope — A reliability model of a radioisotope supply of either the RTE or RTI type remained to be generated when sufficient information was available. It was anticipated that the basic power source would have an inherently high degree of reliability, but that the power management and any necessary power storage equipment would be the prime source of failure.

Inclinometer

An inclinometer mechanization had not yet been modeled. A reliability allocation was assigned to this item, which appeared compatible with possible mechanizations.

DIBSI

DIBSI – The Dynamic Iterative Bearing Strength Instrument modeled, is a two tube configuration employing two pad sizes. The instrument is primarily mechanical. All motors and gear trains are hermetically sealed.

Thermal

The thermal control subsystem model recognizes only the active elements of the subsystem. This includes 12 thermal switches with radiators of the type used on Surveyor and 3 isotope heater pellets. Battery power is not used for heating. The thermal control system is assumed to maintain an ambient temperature between -20 and +50°C for all electronics. With an RTG power source, electrical energy would be available for heating. This alternative has not been factored into the thermal reliability model.

Interconnect

The external harness between boxes and external equipment has been assumed to be 100 conductors. The prime area of interest is at the thermal barrier of the areas which have active temperature control.

Wheel Drive and Steering Subsystem

Wheel Drive and Steering Subsystem mechanisms are hermetically sealed with the exception of three 10 rpm bearings in vacuum in each wheel drive. These external bearings will be dust shielded. The interior of the motor and gearbox housing will be pressurized with an inert gas, such as Nitrogen, for the benefit of all gears, high speed bearings, and motor brushes. Motion will be transmitted externally through bellows seals, however the bellows themselves do not transmit power. The drive motor which the model assumed to be of the DC permag type is anticipated to be the prime source of failure.

Surveyor Basic Bus

In those missions which utilize the Basic Bus during the lunar phase, it was necessary to consider the Basic Bus as a part of the SLRV system. No information was available on Basic Bus reliability, so the predicted reliability of the current configuration of Surveyor was used, excluding the scientific payload. The data source was the JPL Space Programs Summary No. 37-23, Volume 1, dated 30 September 1963. The equivalent lunar day failure rate on a per hour basis was computed from the 80 hour probability of success.

D. FAILURE RATES

Using the classical piece-part summation method of computing equipment reliability, equivalent failure rates on a per hour basis has been established for the equipments of the previous section. These sub-system failure rates are presented in Table IV. 1-1.

Representative piece part failure rates used in the predictions are contained in Table IV. 1-2. These rates are based on GM/RCA experience with high reliability space and military equipment of both electronic and electro-mechanical types, and are considered to be attainable with good design practices.

Table IV. 1-1

SUBSYSTEM FAILURE RATES

Equipment	Failure Rate X 10^{-6} hours (1)		
Vehicle	Operate	Standby	Non-Operate (2)
Tele Communications			
S Band transmitter hi-power mode	132	--	
lo-power mode	42	--	
S Band receiver	15		
VHF Vehicle transmitter hi-power mode	16.5	--	
lo power mode	5.4	--	
VHF Receiver	4.5		
Telemetry	202	--	
Command and Control	375	--	
TV	95	75	
Power Subsystem			
Solar Cell	33	--	
RTG	(2)		
Inclinometer	50	--	
DIBSI	1317	--	
Thermal	12	--	
Interconnect	200		
Wheel Drive (6 units)	918	--	
Steering (2 units)	226	--	
Surveyor			
Basic Bus	801	--	
VHF Transmitter hi-power mode	16.5	--	
VHF Receiver	4.5	--	
Interface	30	--	

(1) Move decimal one place to left for %/1000 hours
(2) Not established

Table IV. 1-2

REPRESENTATIVE PIECE PART FAILURE RATES

General Part Type	Average Failure Rate X 10^{-6} hours
Transistors	0.2
Resistors	0.1
Capacitors	.01
Diodes	0.1
Crystal	0.2
Transformers	1.25
Coils	0.1
Variable Resistors	1.5
DC Motor	100 to 300

E. MISSION RELIABILITY ANALYSIS

The missions analyzed thus far had assumed that failure of any subsystem dictates failure of the mission. This presented a somewhat pessimistic analysis in the quantitative sense, since many of the subsystems had considerable potential in compromised modes of operation. The failure effects study, when completed, was expected to provide information to allow consideration of these compromised modes of operation toward achievement of the mission.

The tradeoff analysis being performed by the systems concept analysis and design group had considered many variables in lunar terrain, mission operation, system configuration, and equipment capabilities. The mission combinations considered numbers in hundreds. Predictions of reliability versus time and/or work were computed for approximately fifty missions.

The system concepts and design group generated time profiles for each of the missions for which a reliability analysis was to be accomplished. As an example, Table IV. 1-3 defines the operating profile for a typical mission study, comparing direct versus indirect communication links with the following ground rules:

a. a locomotion and site search sequence

b. lunar surface model III

c. Goldstone day (12 hour maximum operating)

d. 11 watt solar panel

e. 45° viewing angle on TV

f. 1.33 meters between 10 sec. steering stops

A similar time profile was generated for each mission examined. For missions comparing communications links, the systems configurations of Table IV. 1-4 were used.

Table IV. 1-5 lists a group of missions comparing direct and indirect communications, 45° and 22-1/2° TV fields of coverage, 11 and 22 watt solar panels, and 12 and 24 hour work days. Other parameters which were varied in reliability systems analysis in the early months were, lunar terrain, mission functions (i. e., contour mapping, locomotion, obstacle detection), and function sequences (distance between steering pictures, frequency of 360° TV surveys, etc.).

Figures IV. 1-1 through IV. 1-8 are graphs of probability of success versus distance traveled, or area searched, for the missions of Table IV. 1-5. The lengths of the lines represent the amount of work that can be accomplished in 10 earth days.

Table IV. 1-3 Typical Mission Time-Profile

Function	Direct Link (hrs/ E day)	Indirect Link (hrs/E day)
Vehicle		
Work	3. 61	5. 88
Charge	20. 39	18. 12
Hi Power Transmit	. 51	1. 00
Low Power Transmit	3. 10	4. 88
Receive	24. 00	24. 00
TV Operate	1. 05	1. 76
Telemetry	3. 61	5. 88
Steering Assembly	. 30	. 62
Wheel Drive Assembly	1. 22	2. 73
DIBSI	1. 00	1. 00
Surveyor		
VHF Transmit	-	5. 88
VHF Receive	-	5. 88
Interface	-	5. 88
Basic Bus	-	24. 00

Table IV. 1-4 System Configuration

Direct Link	Indirect Link
Vehicle	Vehicle
Communications-S Band	Communications - VHF
TV-200 x 200 lines	TV-600 x 600 lines
Power-80 watts hours	Power-120 watt hours
Command Control - 100 commands	Command Control - 100 commands
Telemetry - 70 channel	Telemetry - 70 channel
Inclinometer - 2 axis	Inclinometer - 2 axis
DIBSI - Two pads	DIBSI - Two pads
Thermal	Thermal
Interconnect	Interconnect
Wheel Drive - 6 assemblies	Wheel Drive - 6 assemblies
Steering - 2 assemblies	Steering - 2 assemblies
--	Surveyor
--	Basic Bus
--	Communications - VHF
--	Interface

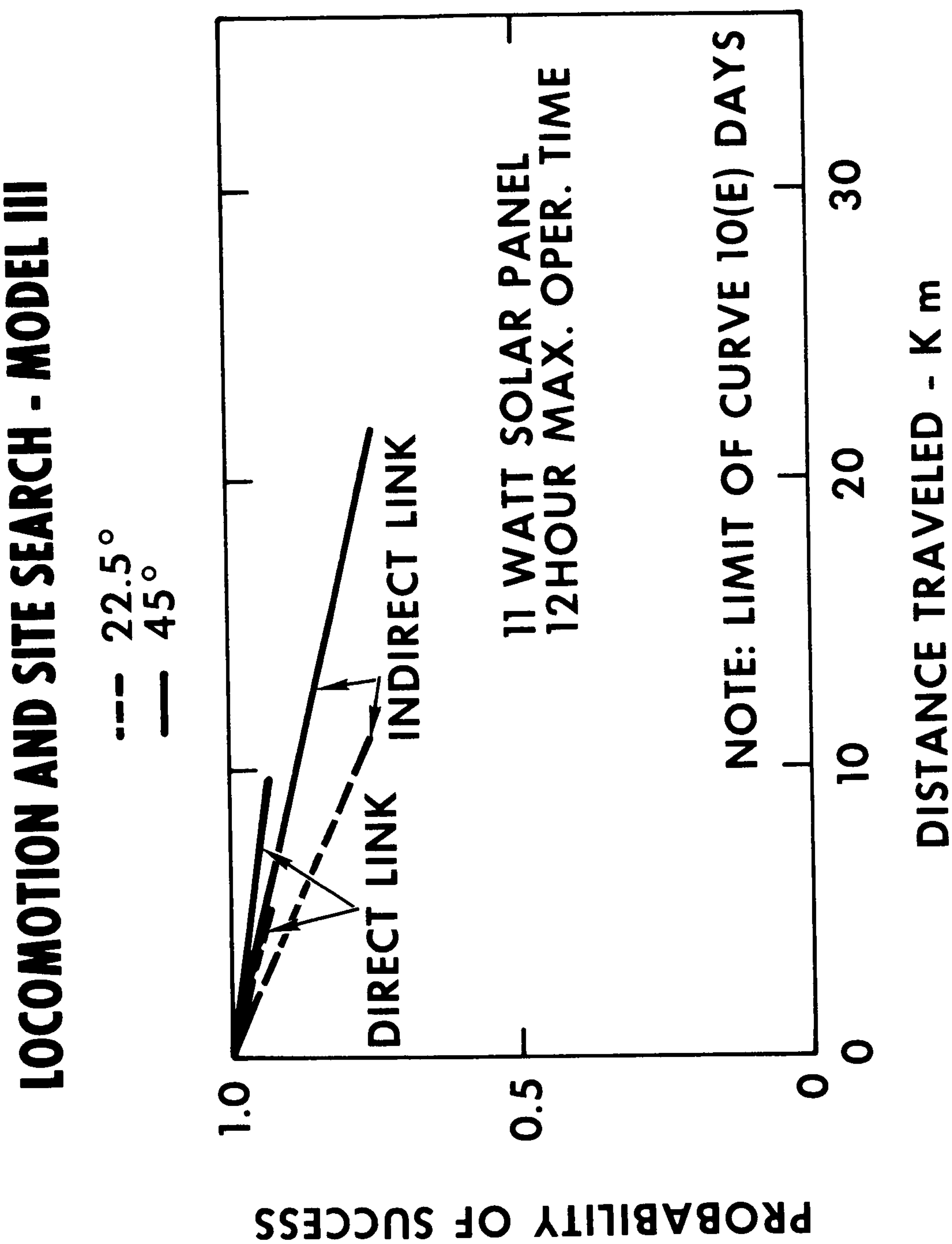

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
DIRECT LINK
INDIRECT LINK
11 WATT SOLAR PANEL
12HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAYS
PROBABILITY OF SUCCESS
1.0
0.5
0
0
10
20
30
DISTANCE TRAVELED - K m

Figure IV.1-1

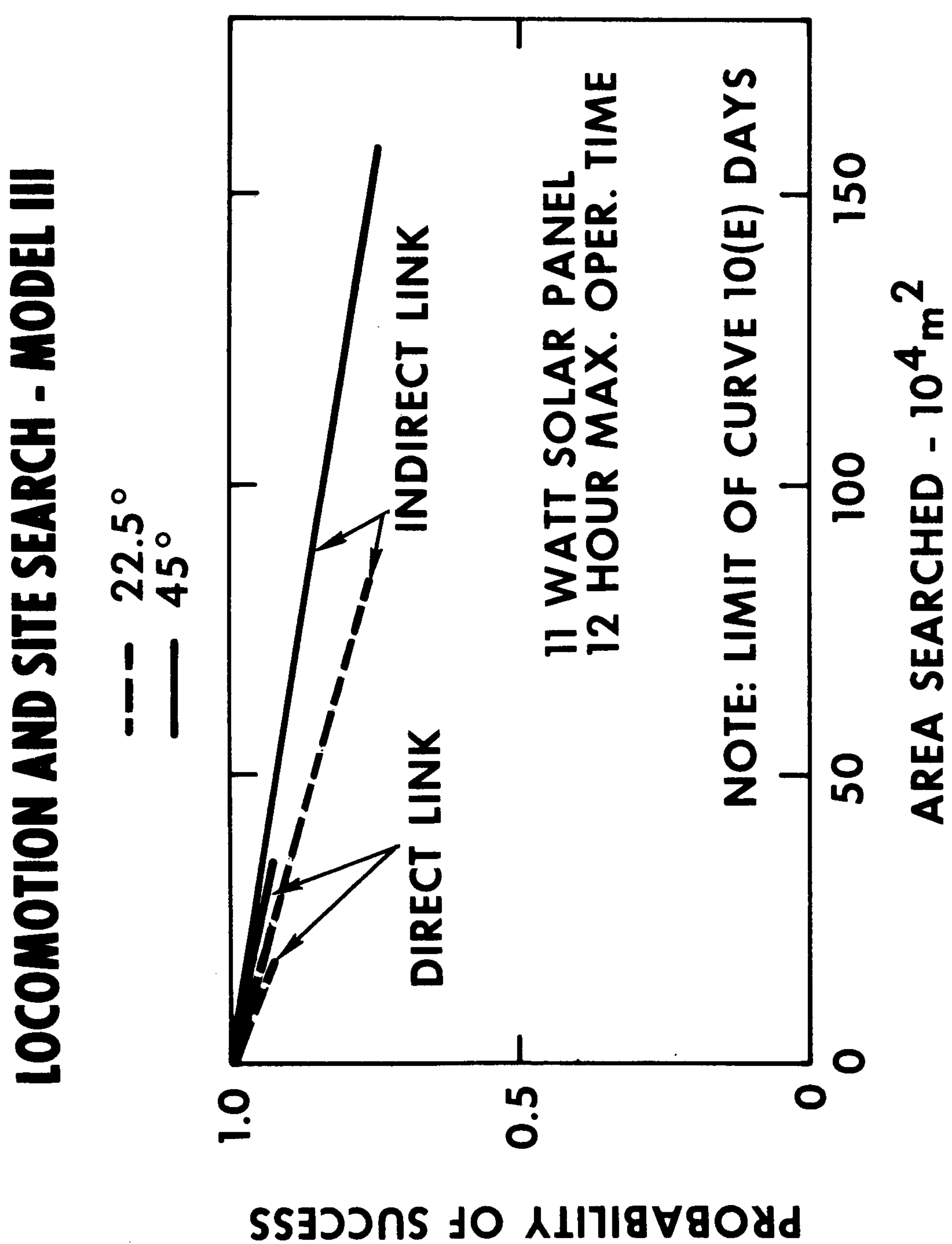

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
INDIRECT LINK
DIRECT LINK
11 WATT SOLAR PANEL
12 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAYS
0
50
100
150
AREA SEARCHED - $10^4 m^2$
1.0
0.5
0
PROBABILITY OF SUCCESS

Figure IV.1-2

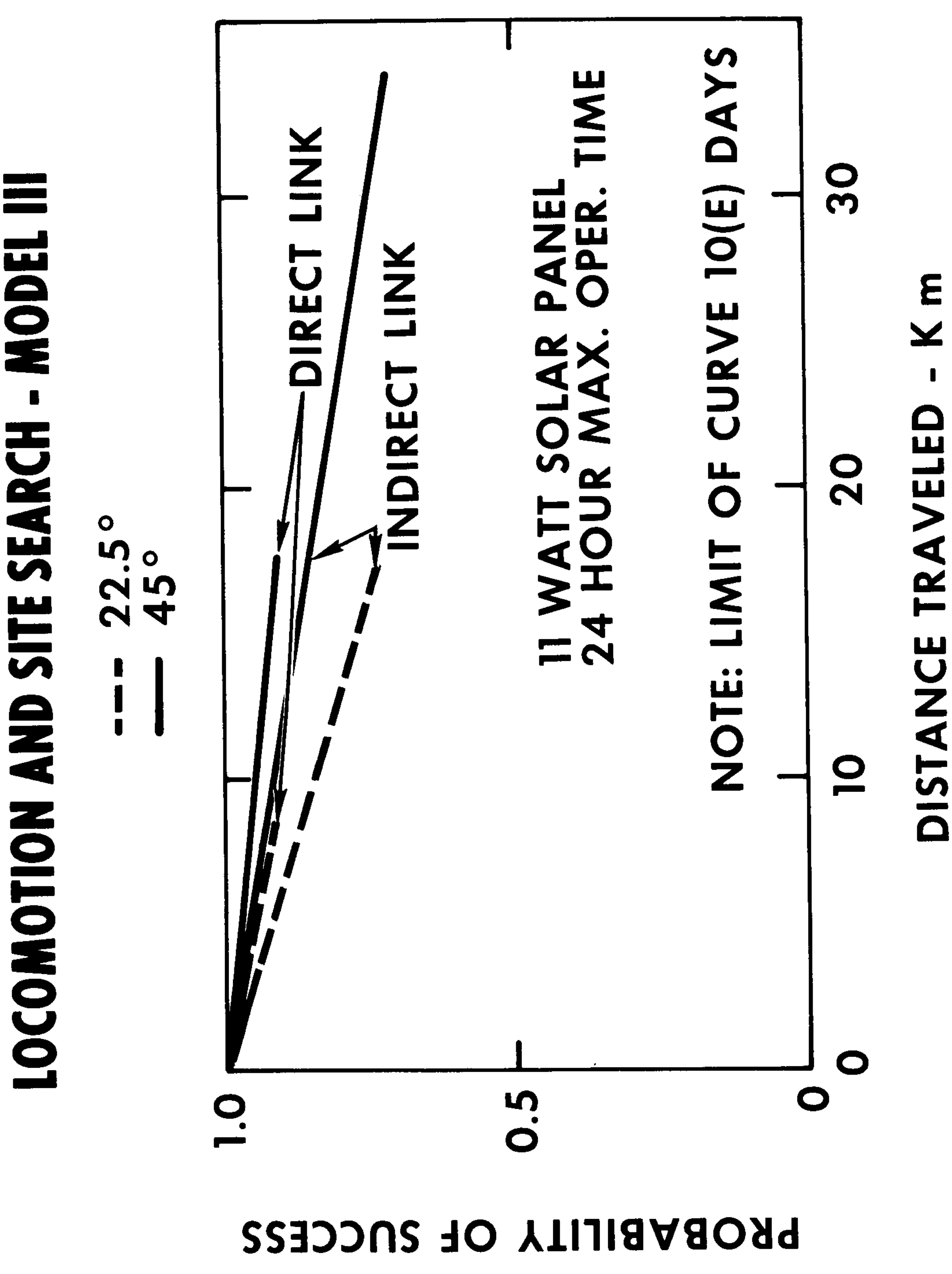

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
DIRECT LINK
INDIRECT LINK
11 WATT SOLAR PANEL
24 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAYS
PROBABILITY OF SUCCESS
1.0
0.5
0
DISTANCE TRAVELED - K m
0
10
20
30

Figure IV. 1-3

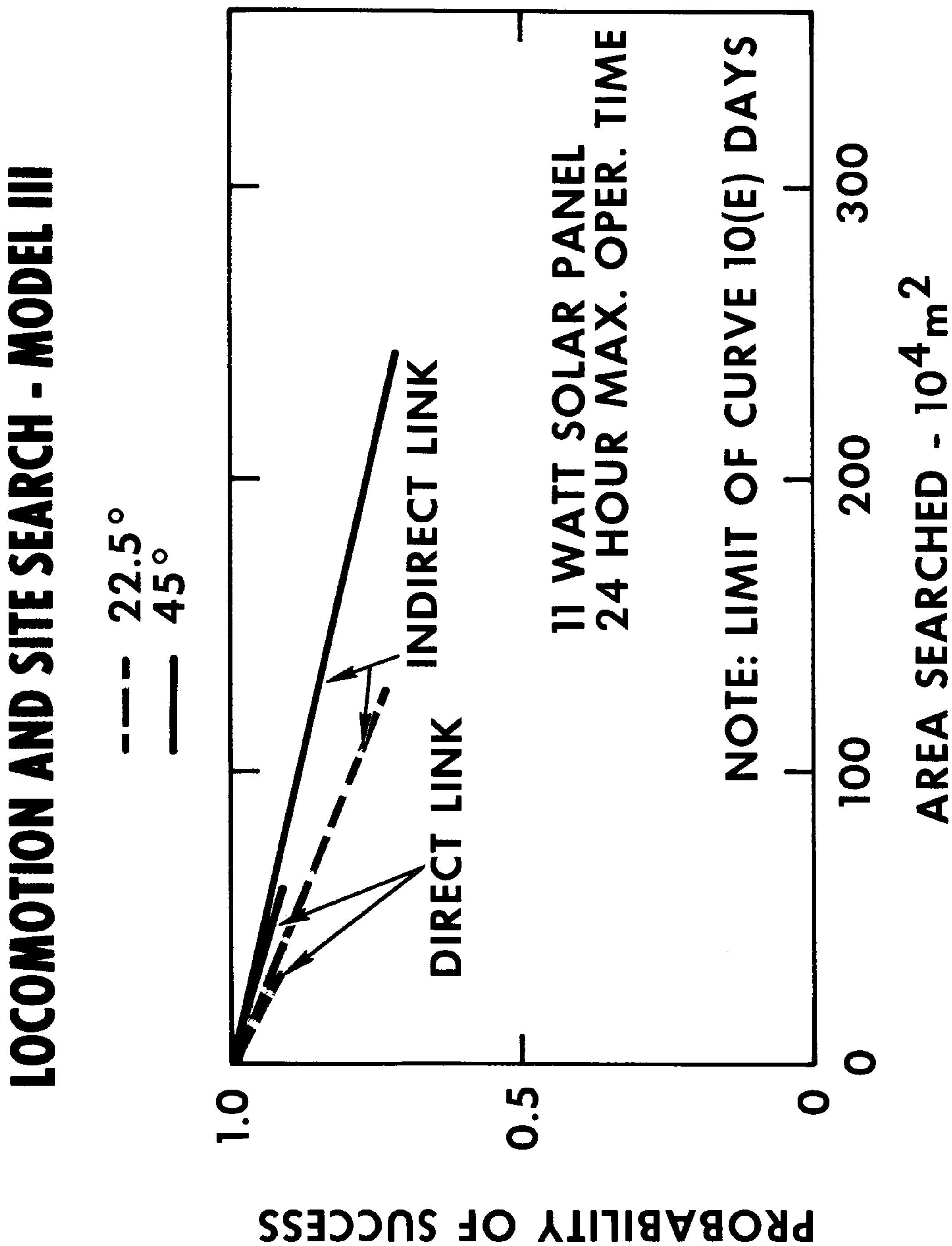

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
INDIRECT LINK
DIRECT LINK
11 WATT SOLAR PANEL
24 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAYS
0
100
200
300
AREA SEARCHED - $10^4 m^2$
PROBABILITY OF SUCCESS
1.0
0.5
0

Figure IV. 1-4

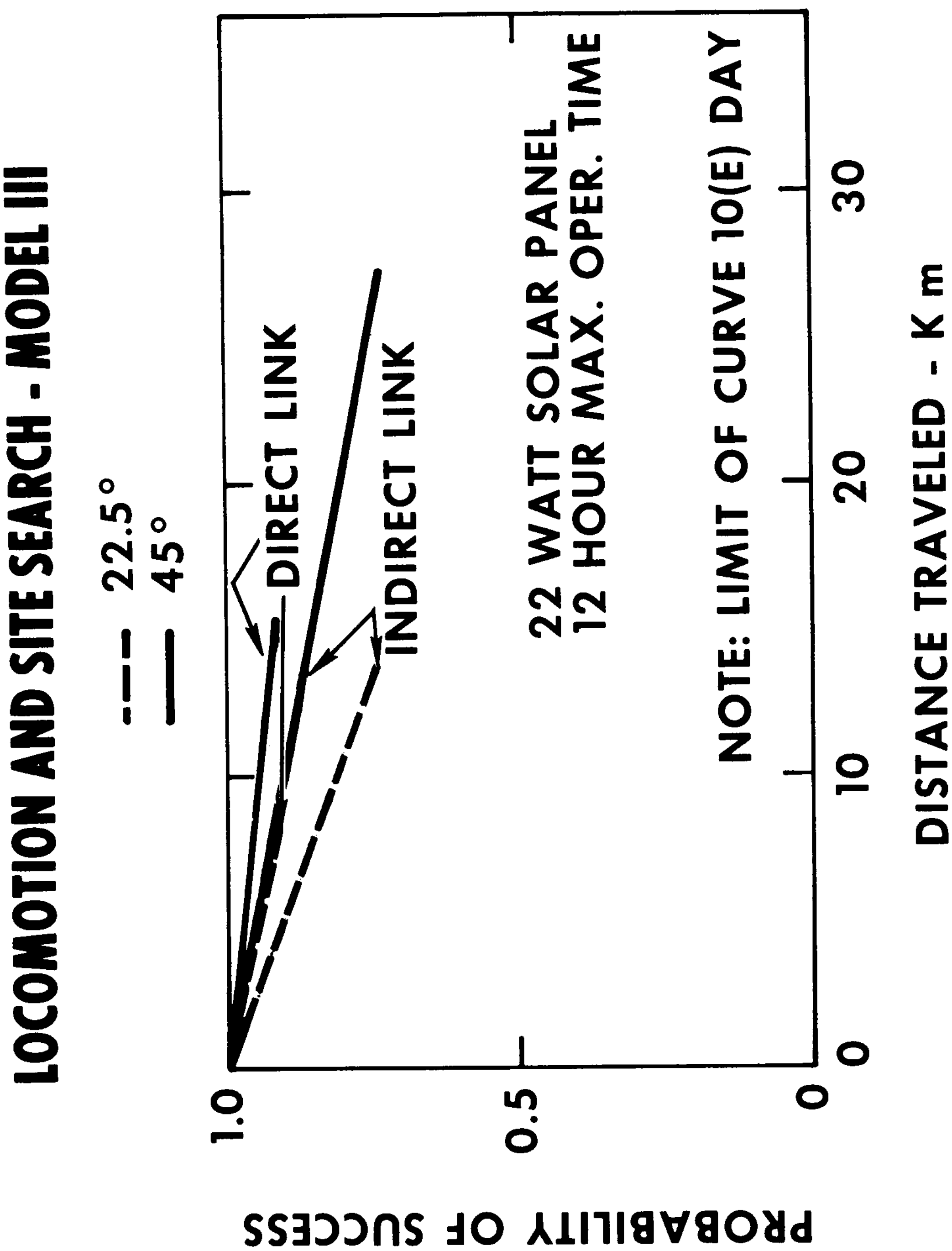

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
DIRECT LINK
INDIRECT LINK
22 WATT SOLAR PANEL
12 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAY
PROBABILITY OF SUCCESS
1.0
0.5
0
0
10
20
30
DISTANCE TRAVELED - K m

Figure IV.1-5

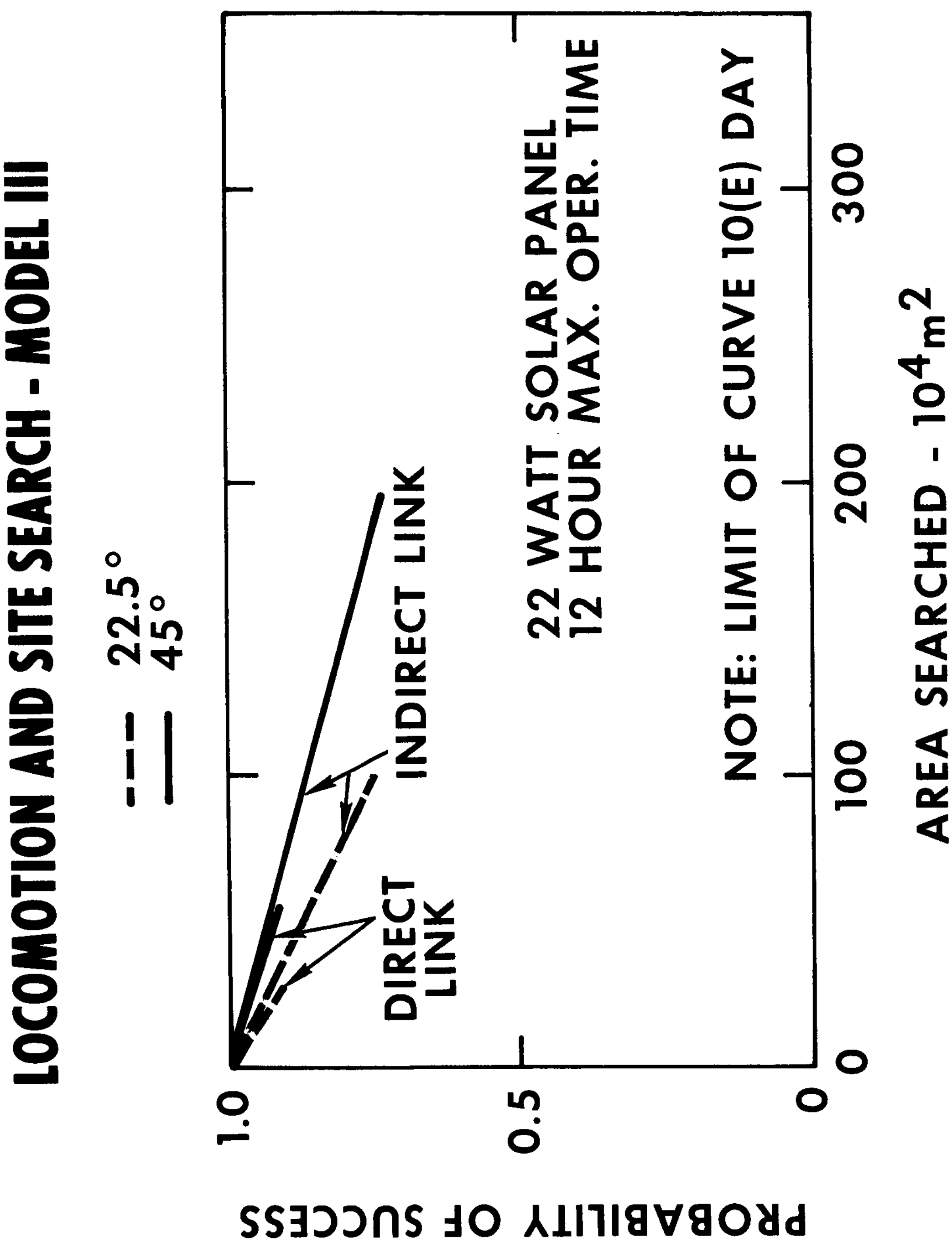

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
INDIRECT LINK
DIRECT LINK
22 WATT SOLAR PANEL
12 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAY
1.0
0.5
0
PROBABILITY OF SUCCESS
0
100
200
300
AREA SEARCHED - 10⁴m²

Figure IV. 1-6

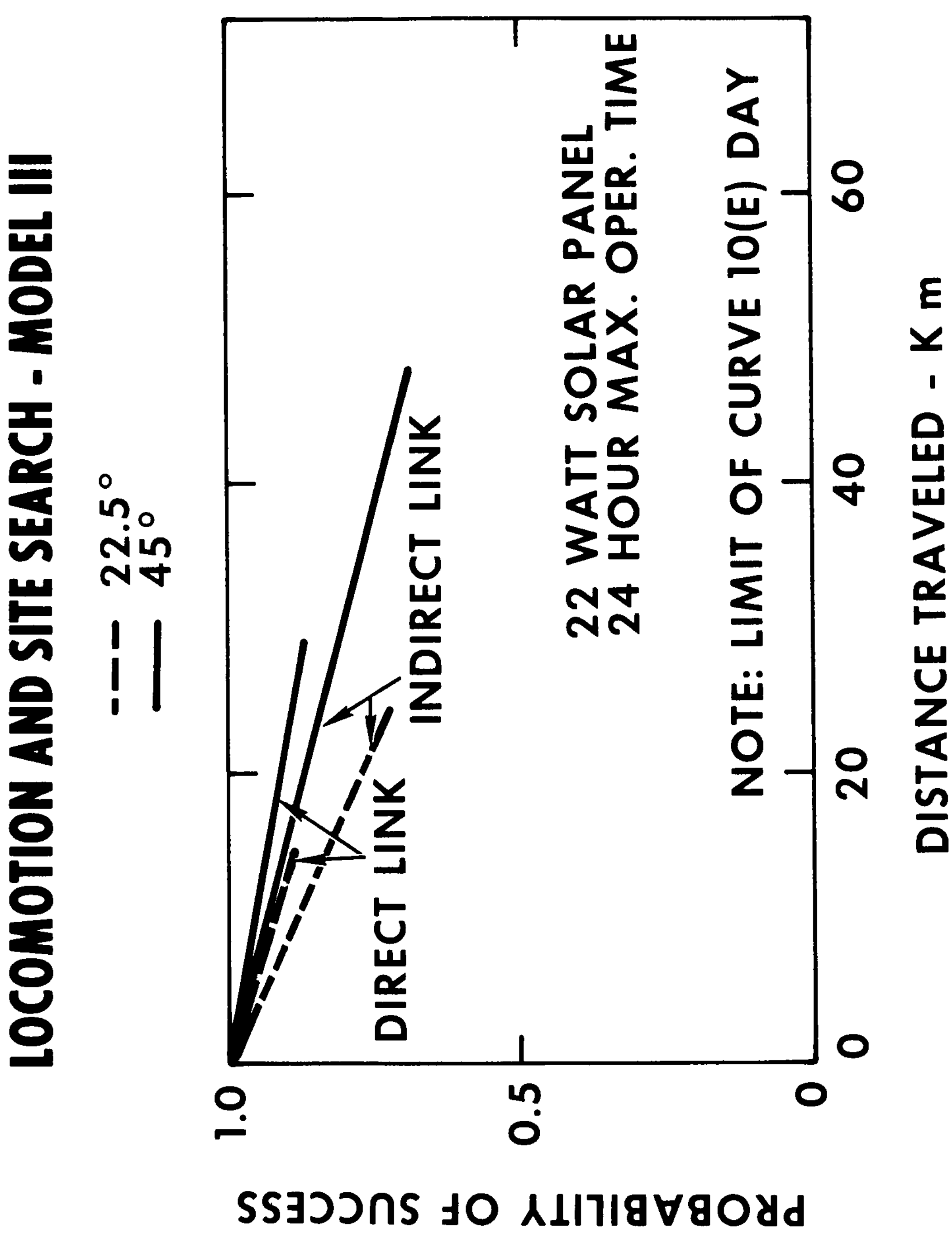

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
INDIRECT LINK
DIRECT LINK
22 WATT SOLAR PANEL
24 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAY
1.0
0.5
0
PROBABILITY OF SUCCESS
0
20
40
60
DISTANCE TRAVELED - K m

Figure IV.1-7

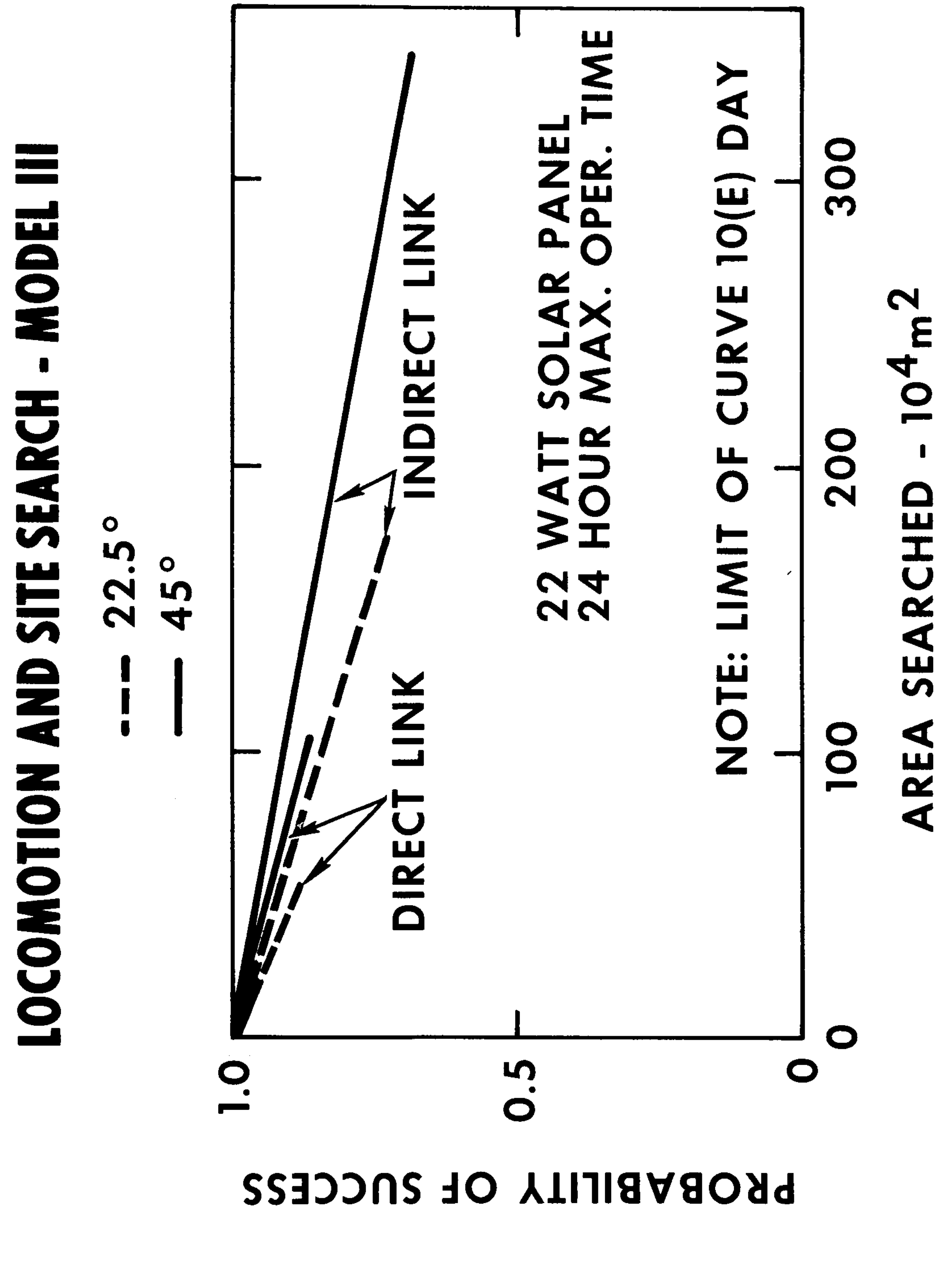

LOCOMOTION AND SITE SEARCH - MODEL III
22.5°
45°
INDIRECT LINK
DIRECT LINK
22 WATT SOLAR PANEL
24 HOUR MAX. OPER. TIME
NOTE: LIMIT OF CURVE 10(E) DAY
1.0
0.5
0
PROBABILITY OF SUCCESS
0
100
200
300
AREA SEARCHED - $10^4 m^2$

Figure IV. 1-8

Table IV. 1-5 Mission Tradeoff Parameters

Mission	Link	TV Angle (degrees)	Solar Panel Power (watts)	Work Day (hours)	Figure No.
1	Direct	45	11	12	1, 2
2	Direct	45	11	24	3, 4
3	Direct	22-1/2	11	12	1, 2
4	Direct	22-1/2	11	24	3, 4
5	Direct	45	22	12	5, 6
6	Direct	45	22	24	7, 8
7	Direct	22-1/2	22	12	5, 6
8	Direct	22-1/2	22	24	7, 8
9	Indirect	45	11	12	1, 2
10	Indirect	45	11	24	3, 4
11	Indirect	22-1/2	11	12	1, 2
12	Indirect	22-1/2	11	24	3, 4
13	Indirect	45	22	12	5, 6
14	Indirect	45	22	24	7, 8
15	Indirect	22-1/2	22	12	5, 6
16	Indirect	22-1/2	22	24	7, 8

F. ANALYSIS COMMENTS

From the early reliability mission analysis, several mission characteristics emerged.

a. The direct communications link either exceeded or was approximately equal to the indirect link in terms of survivability for stated periods of time.

b. The indirect link was more efficient in terms of work accomplished per unit of time, by a factor of 1.5 to 10.

c. The direct link reliability appeared to be a function of available power, or work accomplished, with elapsed time being a minor consideration.

d. The indirect link reliability was strongly influenced by elapsed time, and was somewhat less affected by the amount of work accomplished, in the power ranges considered.

e. With solar power sources, the 24 hour day provided a higher probability of success for a given amount of work than a 12 hour (Goldstone) day.

f. The 45° field of view TV was more efficient than the 22-1/2° unit in most cases.

In the previous statements, all comments had been based on analysis which considered lunar day operation only. Some preliminary work on lunar night survivability indicated that the direct link had a considerably higher survival expectancy, as a result of not being dependent on survival of the Basic Bus. The overall crossover point appeared to be when the direct link efficiency was approximately 1/3 or less than that of the indirect link. Should the indirect link be able to accomplish the mission without having to go through a lunar night, there would be of course, no contest.

In the range of power source capabilities considered, both configurations were very definitely power limited. A small increase in power (say 10%) had different effects on the two systems however. With small power increases, the direct link system experienced the larger percentage gain in efficiency per unit time and adhered to very nearly the same failure rate. The indirect link had a lower percentage of gain in efficiency per unit time, but assumed a lesser failure rate. This increased the desirability of the indirect link with respect to the direct link for any fixed amount or work. The cause of this situation was the very nearly constant contribution to mission failure of the Basic Bus, whether the vehicle is operating or not. The above statements did not necessarily hold for very large increases of power, where the indirect link vehicle may contribute significantly more to mission failure than the Basic Bus.

The reliability advantage which the 45° field exhibits over the 22-1/2° television field of view appear to be the result of having to take fewer pictures to accomplish the stated objectives of the mission under consideration, resulting in less power and time being required per unit of work accomplished.

In summary, at that point in the reliability analysis activity, it appeared that the indirect link was the more desirable of the communications links from a reliability point of view. Any increase in available power which would be obtained would be valuable in either link, but particularly so for the indirect. The 45° field TV appeared superior to the 22-1/2°.

G. LATER STUDIES

The lunar-survey reliability-prediction model was programmed for computer and was included in a group of mission tradeoff studies completed by the Concepts Analysis and Design Group.

The tradeoffs included the following:

Power Supplies

RTG	7.5, 15, 22.5, 30 watts output
Solar Panel	11, 22 watts output

Communications

Direct
Indirect

Television

Field of view	22.5°, 45°
Picture	200 x 200, 600 x 600 lines
Camera height	1, 1.5 meters

Vehicle Velocity

.458 meters/sec, .229 meters/sec

Operating Window

12 hours (Goldstone Only)
24 hours (all 3 DSIF)

Lunar Models

Generally Smooth (Model II)
High Rough Area Fraction (Model III)

Functions

Contour Mapping
Obstacle Detection
Locomotion

A total of 2304 combinations were examined and the 1 E day and 10 E day probabilities of success were computed. These results served as a quick reference for comparative reliability analysis of competing configurations.

The computer listings of these tradeoffs are submitted with this report as a volume of Supplementary Data.

APPENDIX II

RELIABILITY PREDICTIONS

A. INTRODUCTION

Detailed predictions of successful mission accomplishment have been generated for the selected SLRV system configuration. The predictions have been based on the best candidate of the existing detailed designs. In some areas, detailed mechanizations and design data is not available, and the prediction is essentially an allocation based on similar equipment.

B. ENVIRONMENTAL CONSIDERATIONS

General

The temperature extremes on the lunar surface are expected to vary between approximately -160°C to +120°C. This, coupled with the hard-vacuum condition of outer space and possible high-intensity radiation dosages resulting from occasional solar flares, cause concern from a reliability point of view.

Electronics

Most electronics components are capable of surviving storage temperatures ranging from -65°C to +125°C with some components continuing up to a maximum temperature of 200°C. However, their operating temperature range is more limited depending upon their application stress-level. It is necessary, therefore, that the compartment wall temperature be contained during lunar daylight time to a considerably lower value. If a wall temperature can be maintained between 0 to 50°C, then the fairly standard derating policy of RCA can be utilized as a relaibility control criteria. If the upper value of 50°C is exceeded, then additional derating studies will have to be undertaken.

In addition to the temperature problem, power transistors appear to start exhibiting bulk damage, resulting in gain slump-off and leakage-current increases, at radiation dosage levels of about 10^4 Roentgens. They will require special attention during the SLRV Design Study to offset this effect.

Batteries

Batteries are generally critical to temperature and must be controlled to better than 0 to 50°C to obtain reliable operation.

In addition to temperature, batteries are limited-life components depending on the charge-discharge cycles required and the depth and rate of this cycle. Tradeoffs of cycling vs. the expected operation of the equipment have been made and a silver-cadmium battery power subsystem with a mean-cycle life about 600 cycles at a 50% depth of discharge over a +10°C to +50°C operating temperature range is proposed.

Vidicon Tubes

Vidicon tubes are extremely sensitive to temperature during the operate cycle and should be maintained between 0 to +55°C. The lower temperature range for this device is normally -150°C as a storage condition and makes it a marginal element during hibernation which will require special consideration. The vidicon is expected to process about 20,000 TV frames during the mission time and, based on past performance on other programs, this is not expected to be a serious handicap. The final concern for successful operation depends on the cycling rate of the filament; this will be reflected as a shortening of wear-out life because wear-out is inversely proportional to this cycling rate. An effort will be made to define this effect on the vidicon reliability as the program progresses. Present failure rates for this tube are placed at 2 to 4.5 percent per 1000 hours.

Rotating Components

Motors, gear trains, and bearings are affected by temperature and vacuum environment.

The majority of the SLRV rotating components have little or no thermal protection. Most items are at lunar ambient at night (-160°C) and at lunar day ambient (+120°C) plus internal dissipation rises. No operation is expected where the internal ambient is less than 0°F. The very wide temperature range which these items, particularly motors, must survive represent a major reliability task.

Most equipment operates in a contained pressure environment, anticipated to be an inert gas. Loss of pressurization may not be within equipment operating requirements, and very limited life may result. Achievement of rotating life in vacuum would be very beneficial in removing some failure modes. Non-pressurized items, such as the wheel axle bearings, require very careful design consideration during the R & D phase to provide lubrication and bearing sizing which will be adequate for the mission duration.

The DIBSI Force Generator is the only area which is subjected to significant shock and vibration during the lunar survey. The sensitivity of the rotating components to this additional environment has necessitated the use of failure acceleration factors as high as 10.

C. FAILURE RATES

The individual part failure rates form the basic data for the determination of equipment failure rates. The rates used are based on GM/RCA experience with high reliability space and military equipment of both electronic and electro-mechanical types, and are considered to be attainable with good design practices. It has been necessary to modify the failure rates of some equipment to properly accommodate the SLRV environments, most notably temperature.

Table IV. 2-1

REPRESENTATIVE PIECE PART FAILURE RATES

General Part Type	Average Failure Rate X 10^{-6} hours
Transistors	0.2
Resistors	0.1
Capacitors	.01
Diodes	0.1
Crystal	0.2
Transformers	1.25
Coils	0.1
Variable Resistors	1.5
Switches (magnetic)	1.0
Connections	.01
DC Motor	100.

D. RELIABILITY STANDARD MISSION

Reliability analysis early in the SLRV program used numerous mission-search techniques and various configurations of lunar models and equipment in a somewhat generalized manner. As certain conclusions were established, the need became apparent for a complete mission description to support more detailed analysis.

The Reliability Standard Mission was generated to be representative of a wide range of possible missions. In selecting the mission parameters care was taken to include all anticipated types of activity.

To provide a degree of stability in reliability analysis, the mission has been updated only when material changes in mission philosophy occur. As such, the mission does not necessarily always contain the latest mission details.

APPROACH

The mission described recognizes only one task - the certification of a potential LEM landing site. The certification requirement is to determine the availability of a suitable LEM landing point within not more than 300 meters of any point within a circle of 1600 meters radius. The Surveyor Basic Bus may land at any point within the 1600-meter circle.

The mission strategy consists of three phases. They are:

- Locomotion - After landing point is certified, the vehicle vectors to a preferred searching area for the next site.
- Site Search - After arriving in the preferred search area, the vehicle assumes a search mode (consisting of groupings of TV pictures) along the vehicle path until a potential landing point is identified.
- Site Certification - At the potential landing point, the vehicle assumes a contour-mapping mode consisting of several 360° TV picture series, and makes one or more surface-bearing-strength measurements (DIBSI).

After the landing point is certified, the vehicle begins a locomotion phase and the entire cycle is repeated for each landing point.

GROUND RULES

The following ground rules have been used:

a. The surface to be certified has a rough-area percentage of 92. 5.

b. Forty landing points must be certified.

c. The Surveyor Basic Bus lands early during the lunar day.

d. The SLRV uses an indirect VHF communications link to relay data through the Basic Bus.

e. The vehicle power supply is capable of providing 260 watt-hours of usable energy each 24 hours. The supply is a solar-array secondary battery configuration.

f. The TV camera height is one meter. The useful angle of coverage is 45° and the format is 600 x 600 lines. Vertical-axis stereo pairs may be taken by elevating the TV head height.

g. All three DSIF stations are capable of supporting the SLRV mission; this gives a potential operating window of 24 hours.

DETAILED DESCRIPTION OF MISSION

Locomotion - The locomotion phase consists of 500 meters of travel in a relatively straight line to a preferred area of search. A preferred area is an area in which the discovery of a landing point would be beneficial to the efficient performance of the mission. The locomotion sequence consists of one wheel revolution (1.43 m) of travel, one steering picture, a 10-second decision time, a 1.5-second steering step, and then repeat of the sequence. The wheel speed is 10 rpm.

Site Search - The site-search phase averages 80 meters in length. The sequence is one wheel revolution of travel, one steering picture, a 10-second decision time, a 1.5-second steering step, and then repeat of the sequence. A TV sequence of five stereo pairs giving 180° coverage is taken each 21 wheel rotations (30 m). The effective TV radius of view is 30 meters.

Site Certification - Site certification consists of two activities: contour mapping, and DIBSI experiments. Prior to contour mapping, a series of 5 stereo pairs are taken from the edge of the prospective landing point. The vehicle then moves into the central area of the landing point and takes TV surveys from three separate stations. The picture sequence is:

Station 1	10 stereo pairs
Station 2	1 stereo pair, 9 single frames
Station 3	1 stereo pair, 9 single frames

The average travel distance per landing point for the certification phase is 30 meters.

An average of 1.5 DIBSI experiments are performed for each landing point for a mission total of 60. Each DIBSI experiment requires 6 TV frames.

MISSION SUMMARY

The Standard Reliability Mission can be accomplished in 9 earth days. This assumes no equipment failure and no thermal operating limitations anywhere in the system.

Table IV.2-2 lists some of the computed mission values. It should be noted that all velocity and power averages are averaged for work time only, and do not include charge time.

Table IV.2-3 is a profile of equipment operating time.

Table IV.2-2

RELIABILITY STANDARD MISSION CHARACTERISTICS

	Loco	Search	Site Cert.	DIBSE	Mission
Average Velocity (m/sec)	0.74	0.71	0.79	0.0	0.69
Average Travel per Landing Point (meters)	500.	80.	30.	0.0	610.
Total Travel (meters)	20,000	3,200	1,200	0.0	24,400
TV Frames Total	14,000	3,400	2,080	360	19,840
Average Power (watts)	24.27	24.52	30.70	11.70	23.73
Energy/Landing Point (watt hours)	45.60	7.67	3.30	1.75	58.32
Total Energy (watt hours)	1,802.5	306.0	131.9	70.2	3210.6
Average Work Time/E day (hours)	8.34	1.39	.48	.67	10.88
Mission Work Time Total (hours)	75.06	12.52	4.30	6.00	97.88

Table IV. 2-3

PROFILE OF EQUIPMENT OPERATING TIME

	Average Time per E day (hours)	Mission Total Time (hours)
Work Time	10.88	97.88
Charge Time	13.12	118.12
Wheel Drive	3.17	28.50
Steering	.79	7.12
Transmit (vehicle)		
hi-power	.72	6.46
lo-power	10.16	91.42
Receive (vehicle)	24.00	216.00
TV	2.16	19.40
DIBSI	.67	6.00
Surveyor SLRV Equipment	10.88	97.88
Surveyor Basic Bus	24.00	216.00

E. SLRV RELIABILITY PREDICTION - Lunar Phase

The system configuration used for the prediction work is that of the indirect link. It consists of:

- A power and control group with a VHF communication link, a Surveyor-compatible command and control subsystem, and a stationary solar-array secondary-battery power subsystem.
- An instrumentation group, made up of a single-vidicon stereo TV, a two-tube DIBSI, an all-solid-state multiplexing telemetering subsystem, and a two-axis electro-mechanical clinometer.
- A basic vehicle, comprised of six wheel-and-drive assemblies with all high-speed components hermetically sealed, two all-hermetically-sealed steering assemblies, a thermal-control subsystem with the active components consisting of radioisotope heating pellets and Surveyor-type thermal switches, interconnect cabling, and vehicle structures.
- The Surveyor itself, which includes that equipment unique to the SLRV, namely, VHF communications, range and bearing, Surveyor interface, and the Surveyor basic bus.

The system is diagrammed in Figure IV. 2-1.

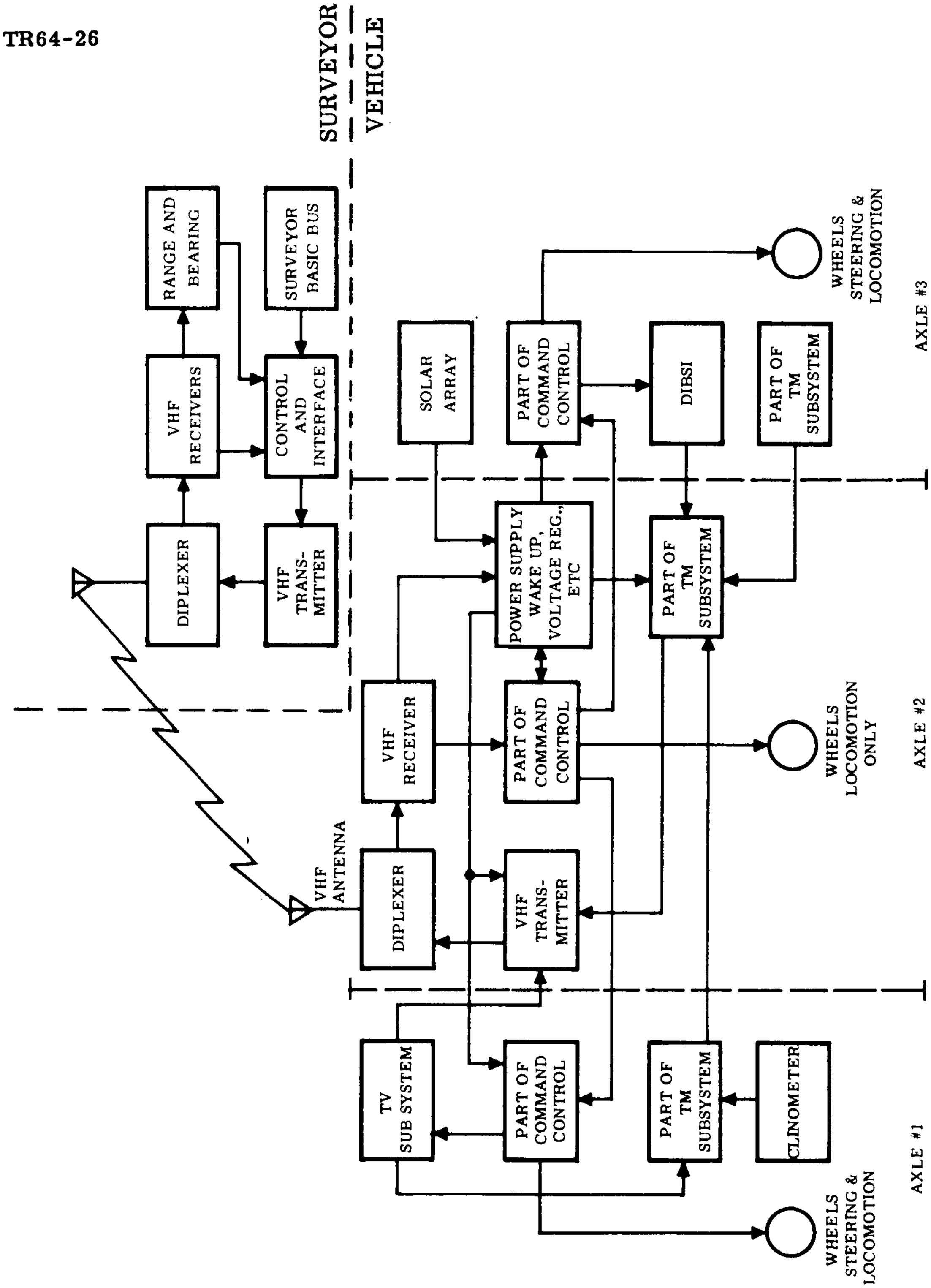


Figure IV.2-1 Simplified Conceptual Diagram of Proposed System Configuration for the SLRV

1) SLRV (excluding basic bus)

The form of the prediction model is:

$$P_s = P_{day} P_{night}$$

where

P_s = Probability of successful mission completion.

P_{day} = Probability of successful completion of lunar-day portion of mission.

P_{night} = Probability of surviving lunar night.

1a Lunar Day

The probability of successfully completing the lunar-day portion of the mission is:

$$P_{day} = e^{-\Sigma\lambda t}$$

where

$$\Sigma\lambda t = \Sigma\lambda_1 t_1 + \Sigma\lambda_2 t_2 + \Sigma\lambda_3 t_3$$

λ_1 = the operating failure rate of equipment considered.

t_1 = the time of equipment operation with λ_1 failure rate.

λ_2 = the operating failure rate of equipment operating in a mode other than that associated with λ_1.

t_2 = the time of equipment operation with λ_2 failure rate.

λ_3 = the non-operative failure rate of equipment during the lunar day. λ_3 was selected as .01 of λ_1 for electronic equipment, and .001 for λ_1 for mechanical equipment.

t_3 = the non-operating time of the equipment associated with λ_3 failure rate.

Detailed reliability predictions for the SLRV system when operating during the lunar day to profiles similar to the reliability standard mission are presented in Tables IV.2-4 through IV.2-16.

Table IV.2-4

ASSEMBLY FAILURE RATES - POWER SUPPLY SUBSYSTEM

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour	
		At Approx. -10°C to +10°C	At Approx. +40°C to +60°C
Series Regulator			
Pwr. (Pass) Transistor	1	0.050	0.075
Transistor (Driver)	1	0.050	0.075
Zener/diode	1	0.040	0.060
Transistor (Low Pwr)	1	0.020	0.040
Resistors	4	0.004	0.008
Sensistor	1	0.010	0.010
Sub-Total	9	0.174	0.268
Shunt Regulator			
Pwr. Transistor	1	0.050	0.075
Transistors (Low Pwr)	3	0.060	0.120
Pwr. Resistor (W.W.)	1	0.010	0.015
Resistors	5	0.005	0.010
Zener/diode	1	0.040	0.060
Sensistor	2	0.020	0.020
Fuze	1	0.010	0.010
Sub-Total	14	0.195	0.310
Converter			
Pwr. Transistors	2	0.050	0.100
Diodes	4	0.040	0.060
Transformers	1	0.030	0.050
Full Wave Rectifier Assy's.	4	0.040	0.060
Inductors	2	0.050	0.080
Resistors	10	0.010	0.020
Diodes (Zener)	1	0.040	0.040
Transistor (Low Pwr.)	2	0.040	0.060
Capacitors	5	0.005	0.005
Saturable Reactor	2	0.060	0.100
Sub-Total	39	0.365	0.475

Table IV. 2-4

ASSEMBLY FAILURE RATES - POWER SUPPLY SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour	
		At Approx. -10°C to +10°C	At Approx. +40°C to +60°C
State of Charge Monitor and Battery Amp Hour Monitor			
Transistors	6	0.120	0.240
Diodes	9	0.090	0.180
Resistors	16	0.016	0.032
Transformer	1	0.030	0.050
Magnetic Amplifier	2	0.100	0.120
Capacitors (Tantalytic)	3	0.009	0.030
Capacitors	2	0.002	0.002
Diode (PnPn)	1	0.020	0.040
Sub-Total	40	0.387	0.694
Reversible Counter			
Transistor	2	0.040	0.080
Diodes	9	0.090	0.180
Resistors	12	0.012	0.024
Capacitors	4	0.004	0.004
Sub-Total	27	0.146	0.288
Solar Array			
Shingles (5 cells)	23 x		

Individual solar cell failure rate of 0.01×10^{-5} /hour is typical. With 23 shingles in series and an array of approx. 30 of these series arrangements in parallel with diode insolation, but with only about 15 operating at any given time, the probability of a series shingle arrangement lasting for 14 earth days is 0.9436. For at least fourteen surviving, it is 0.9985, and for at least thirteen surviving, it is 0.999. These estimates have been based upon half of the array (15) because as a nominal value only 50% will be contributing.

Table IV.2-5

FAILURE RATE SUMMARY - POWER SUBSYSTEM (SOLAR ARRAY)

Power Supply	Failure Rate in Failures Per Hour Approx. x10 ^{5}		Number of Times Per Earth Day Entering This State			Number of Times Per Lunar Day Entering This State			Times Per Earth Day In This State (Hours)			Times Per Lunar Day In This State (Hours)			P_s For One Lunar Day (14 Earth Days) -10 Days Operate	P_s For One Complete Lunar Day (28 Earth Days)	Notes
Subsystem	-10°C to +10°C	+40°C to +60°C	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On			
Series Regulator	0.174	0.268	< 1	NA	< 1	3	NA	2	~ 7	~ 10	~ 7	96	140	100	0.9994	0.9994	This reflects a lower power operating level of the regulator
Shunt Regulator	0.195	0.310	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240	0.9993	0.9993	
Converter	0.365	0.475	< 1	NA	< 1	3	NA	2	~ 7	~ 10	~ 7	96	140	100	0.9989	0.9989	
Solar Array	The solar array consists of 30 parallel sets of series groups of 23 shingles. Each shingle is a 5-solar-cell unit. Based upon a basic solar cell failure rate of 0.01 failures per 10^5 hours (0.01 x 10^5 failures per hour). The following probabilities have been generated (assumes 15 cells nominally operating). P_s of complete array of 15 only. = 0.9436 P_s of at least 14 of 15 = 0.9985 P_s of at least 13 of 15 = 0.999														0.999	0.998	The reliability given is for catastrophic failures. It is assumed that sufficient over-capacity has been designed in to allow both for degradation and some level of catastrophic failure.
Batteries	The battery is assumed to consist of two 13-cell series strings of 100% capacity, Ag-Cd operated up to 50% depth of discharge over a temperature range of +10°C to +60°C. This yields a cycle life of approx. 600 with a standard deviation, σ, of approx. 200. Assuming a mission cycle life of 100 cycles results in a mission cycle at approx. 2.5σ. The failure probability due to cycling is		~ 7	NA	~ 7	*100	NA	100	~ 16*	NA	~ 7	*226	NA	100	0.9918	0.9910	
State of Charge Monitor and Battery Amp-hour Monitor	0.387	0.694	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240	0.9984	0.9984	
Reversible Counter	0.146	0.288	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240	0.9993	0.9993	
Subtotal not including State of Charge Monitor															0.988	0.986	
Subtotal including State of Charge Monitor															0.986	0.984	

*Denotes charge mode rather than off.

Table IV.2-6

FAILURE RATE SUMMARY - COMMUNICATIONS SUBSYSTEM

Communications Subsystem	Failure Rate in Failures Per Hour Approx. $\times 10^5$		Number of Times Per Earth Day Entering This State			Number of Times Per Lunar Day Entering This State			Times per Earth Day In This State (Hours)			Times per Lunar Day In This State (Hours)			P_s For One Lunar Day (14 Earth Days) -10 Days Operate	P_s For One Complete Lunar Day (28 Earth Days)	Notes
	-10°C to +10°C	-40°C to +60°C	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On			
Command Rcv'r																	
RF Amplifier	0.123	0.133	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240			① This is an average value of off time during 14 earth days. In reality this unit is on continuously for approx. two-five day intervals.
Local Osc.	0.124	0.134	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240			
Mixer	0.124	0.134	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240			
IF Strip	0.462	0.532	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240			
Demod & AGC	0.172	0.182	< 1	NA	< 1	3	NA	2	~ 7	NA	~ 17	96	NA	240			
Subtotal	1.005	1.115	< 1①	NA	< 1①	3	NA	2	~ 7	NA	~ 17①	96②	NA	240	0.9973	0.9972	
NB/WB SW.	0.100	0.100										146	NA	~190	0.9998		② The failure rate of circuits and components in the off state have been assumed to be 1% of the operable state except where otherwise noted.
Total	1.105	1.215										146	NA	~190	0.9971	0.9970	
Antenna Ass'y																	
Diplexer *	0.150	0.200	< 1①	NA	< 1①	3	NA	2	~ 7①	NA	~ 17①	96②	NA	240			
Antenna	0.010	0.010	< 1①	NA	< 1①	3	NA	2	~ 7①	NA	~ 17①	96②	NA	240			
Total	0.160	0.210										96②	NA	240	0.9995	0.9988	
Transmitter																	
DC to DC Conv.	0.233	0.283	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
X3 Multiplier	0.404	0.524	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
Osc.-Mod.	0.314	0.419	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
Amplifier	0.156	0.176	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
X2 Multiplier	0.200	0.260	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
Filter	0.039	0.039	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
Subtotal	1.346	1.701	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2	0.9997	0.9996	
High Pwr Stage and Switching	0.250	0.250	≪1	NA	≪1	~ 2	NA	~ 2	< 24	NA	Neg.	~336	NA	<1 Est	0.9999	0.9998	
Total	1.596	1.951	≪1	NA	≪1	~ 2	NA	~ 2	< 24	NA	Neg.	~336	NA	<1 Est	0.9996	0.9994	
DIBSI Data Processor																	
Summer	0.050	0.100	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
SCO No. 1	0.260	0.360	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
SCO No. 2	0.260	0.360	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
SW No. 1	0.100	0.120	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
SW No. 2	0.100	0.120	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
Calibrate	0.065	0.075	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27			
Total	0.835	1.135	7	NA	6	81	NA	80	23.7	NA	~0.31	331+	NA	4.27	0.9999	0.9998	
Rcv'r Input Selector	0.100	0.100	(Same as Command Receiver)												0.9999	0.9998	
Surveyor Based Rover Communi-cations																	
Antenna	0.015	0.015	(Same as Command Receiver — Low Power Configuration of Transmitter used) Sub-Total for these Components														
Diplexer	0.175	0.225															
VHF Xmittr																	
Lo Pwr	1.346	1.701												240	0.9952	0.9944	
Hi-Pwr	1.596	1.951															
VHF Rcv'r																	
Range & Bear	0.833	0.933	7	NA	6	81	NA	80	~24	NA	Neg.	~336	NA	.05	0.9999	0.9998	
VHF Rcv'r	1.230	1.350	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2	0.9997	0.9996	
Inputs H & L	0.400	0.480	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
Input W #2	0.300	0.360	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2	0.9998	0.9997	
Preselector	0.300	0.360	1.23×10^3	NA	1.23×10^3	17.2×10^3	NA	17.2×10^3	22.63	NA	1.37	316.8	NA	19.2			
R&B Ckt.																	
200kc Osc.	0.080	0.146	Same as Range & Bearing Rcv'r Substantially														
2-Gates	0.048	0.094															
2-Amp.-Lim.	0.182	0.364															
Flip-flop	0.070	0.140													0.9999	0.9998	
Regulator	0.052	0.070															
Lo Pass Filter	0.001	0.001															
Total	5.052	6.239													0.991	0.988	

Table IV. 2-7

ASSEMBLY FAILURE RATES - COMMAND AND CONTROL SUBSYSTEM (COMPATIBLE SYSTEM WITH PARALLEL DATA TRANSFER)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{6} From ~ 0°C to + 60°C
Vehicle Central Decoder (VCD)		
Drivers	14	1.764
One Shots	5	0.120
Trigger FF's	16	0.384
Free Running FF's	10	0.120
Four Input Gates	12	0.144
Three Input Gates	6	0.072
Two Input Gates	14	0.168
Inverters	4	0.048
Schmidt Triggers	3	0.072
Diode Clusters	5	0.400
Level Set	3	0.144
Subtotal		4.336
VSD's - Axle #1		
Drivers	17	2.142
One Shots	8	0.192
FF's	10	0.240
Four Input Gates	2	0.024
Three Input Gates	11	0.132
Two Input Gates	26	0.312
Inverters	17	0.204
Diode Clusters	9	0.720
Relays	9	*
Relay Drivers	9	1.134
Five Input Gates	3	0.036
Subtotal, Not Including Relays		5.136
VSD's - Axle #2		
Drivers	32	4.032
One Shots	10	0.240
FF's	27	0.648
Four Input Gates	3	0.036
Three Input Gates	20	0.240
Two Input Gates	38	0.384
Inverters	35	0.348
Diode Clusters	9	0.720
Relays	14	*
Relay Drivers	14	1.764
Five Input Gates	2	0.024
Subtotal		8.436
Subtotal VSD's		13.572 and 0.46%/1000 Operations for Relays
Total VSD's and VCD		17.908 and 0.46%/1000 Operations for Relays

*This failure rate is in percent failures anticipated in 1000 operations. For each relay it is 0.02%.

Table IV.2-8

FAILURE RATE SUMMARY - COMMAND AND CONTROL SUBSYSTEM

Command Control Subsystem	Failure Rate in Failures Per Hour		Number of Times Per Earth Day Entering This State			Number of Times Per Lunar Day Entering This State			Times Per Earth Day in This State (Hours)			Times Per Lunar Day In This State (Hours)			P_s For One Lunar Day (14 Earth Days) -10 Days Operate	P_s For One Complete Lunar Day (28 Earth Days)	Notes
	-10°C to +10°C	-40°C to +60°C	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On			
Vehicle Central Decoder	4.336×10^5		< 1	NA	< 1	3	NA	2	~ 7	NA	~17	96	NA	240	0.9892 (1)	0.9875	(1) Assumed failure rate of most modules used is: "off" failure rate = 10% of "on" failure rate.
VSD's — Axle No. 1, Exclusive of relays	5.136×10^5		>2<3	NA	>2 < 3	~ 31	NA	~ 30	~17	NA	~ 7	226	NA	100	0.9937	0.9920	
Axle No. 2, Exclusive of relays	8.436×15^5	Same as above													0.9898	0.9870	
Relays (23) Locomotion Control (15)	15×10^5	failures per hour	~ 600 per relay	NA	~ 600 per relay	~ 9000 per relay	NA	~ 9000 per relay	NA	NA	NA	NA	NA	NA	0.9851	0.9851	
Steering Control (4)	4×10^5	failures per hour	Same as above												0.9960	0.9960	
Azimuth Control (4)	0.05×10^5	failures per hour	> 2 < 3	NA	>2< 3	~ 30	NA	~ 30	NA	NA	NA	NA	NA	NA	0.9999	0.9999	
Total															0.9546	0.949	

Table IV.2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM

Assembly and Component-Part Type	Part Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} @ ~ (-10°C to +10°C)	Failure Rate in Failures Per Hour x 10^{-5} @ ~ (+40°C to +60°C)
Regulated Power Supply			
Power Transistor	1	0.02	0.050
Lo-Power Transistor	4	0.08	0.160
Diode	1	0.01	0.020
Capacitor, Tantalum	2	0.002	0.020
Capacitor, Mica	1	0.001	0.001
Resistor, Composition	10	0.010	0.020
Potentiometer	1	0.15	0.150
R. F. Choke	2	0.02	0.060
Subtotal		0.293	0.481
Horizontal Blanking Generator			
Transistor	2	0.04	0.080
Potentiometer	1	0.15	0.150
Resistor, Composition	3	0.003	0.006
Resistor, W. W.	4	0.004	0.014
Capacitor	1	0.001	0.001
Subtotal		0.198	0.251
Horizontal Sync and Sweep Generator			
Transistors	6	0.12	0.240
Resistors, Composition	14	0.014	0.028
Resistors, W. W.	6	0.006	0.084
Diodes	3	0.03	0.060
Capacitors	4	0.004	0.004
Potentiometer	2	0.30	0.300
Subtotal		0.474	0.716

Table IV. 2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-6}	
		@ ~ (-10°C to +10°C)	@ ~ (+40°C to +60°C)
Horizontal Deflection Amplifier			
Transistors	5	0.10	0.200
Diodes	3	0.03	0.060
Capacitors, Tantalum	2	0.002	0.020
Capacitors, Mica	2	0.002	0.002
Resistors, Composition	12	0.012	0.024
Resistors, W. W.	3	0.003	0.052
Subtotal		0.119	0.358
÷ 2 SYNC			
Transistors	2	0.04	0.080
Diodes	2	0.02	0.040
Capacitors	2	0.002	0.004
Resistors	7	0.007	0.014
Subtotal		0.069	0.138
Vertical Erase Osc./Read SYNC Osc.			
RF Choke	1	0.01	0.030
Capacitors	3	0.003	0.003
Diodes	2	0.02	0.040
Transistors	2	0.04	0.080
Resistors	6	0.006	0.012
Subtotal		0.079	0.165
Vidicon Prepare - Read Gate			
Diodes	3	0.03	0.060
Transistors	3	0.06	0.120
Resistors	10	0.01	0.020
Subtotal		0.10	0.200

Table IV.2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} @ ~ (-10°C to +10°C)	@ ~ (+40°C to +60°C)
Beam Current Regulator			
Diodes	2	0.02	0.040
Potentiometer	1	0.15	0.150
Transistor	2	0.04	0.080
Resistors, Composition	5	0.005	0.010
Resistors, W. W.	2	0.002	0.028
Subtotal		0.217	0.308
HV Converter			
Transistors	7	0.14	0.350
Diodes	7	0.07	0.140
Capacitors	9	0.009	0.018
Resistors, Composition	22	0.022	0.044
Resistors, W. W.	7	0.007	0.098
H. V. Xtmr (Toroid)	1	0.01	0.060
Subtotal		0.258	0.710
Focus Current Regulator			
Transistors	5	0.10	0.210
Diodes	1	0.01	0.020
Resistors, Composition	7	0.007	0.014
Resistors, W. W.	3	0.003	0.042
Potentiometer	1	0.15	0.150
Capacitor	1	0.001	0.002
Subtotal		0.271	0.438
Blanking Mixer			
Diodes	3	0.03	0.060
Transistors	1	0.02	0.040
Capacitors	1	0.001	0.002
Resistors	6	0.006	0.012
Subtotal		0.057	0.114

Table IV. 2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-6} @ ~ (-10°C to +10°C)	@ ~ (+40°C to +60°C)
Horizontal Erase Oscillator			
Transistors	3	0.06	0.120
Resistors	9	0.009	0.018
Capacitors, Paper	2	0.002	0.004
Capacitors, Tantalum	1	0.001	0.010
Diodes	1	0.01	0.020
Subtotal		0.082	0.172
Vertical Blanking Generator			
Transistors	4	0.08	0.160
Capacitors, Mica	2	0.002	0.002
Capacitors, Paper	2	0.002	0.004
Capacitors, Tantalum	2	0.002	0.020
Resistors, Composition	8	0.008	0.016
Resistors, W. W.	6	0.006	0.084
Subtotal		0.100	0.286
Vertical Sweep Generator			
Transistors	5	0.10	0.200
Resistors, Composition	12	0.012	0.024
Resistors, W. W.	5	0.005	0.070
Diodes	3	0.030	0.060
Capacitors, Mica	1	0.001	0.001
Capacitors, Paper	2	0.002	0.004
Potentiometer	1	0.150	0.150
Subtotal		0.300	0.509

Table IV.2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} @~ (-10°C to +10°C)	Failure Rate in Failures Per Hour x 10^{-5} @~ (+40°C to +60°C)
Vert. Defl. Amp.			
Transistors	4	0.080	0.250
Resistors, Composition	8	0.008	0.016
Resistors, W. W.	6	0.006	0.084
Potentiometer	1	0.150	0.150
Capacitors, Mica	1	0.001	0.001
Capacitors, Tantalum	1	0.001	0.010
Subtotal		0.246	0.511
Video Preamp			
Transistors	4	0.080	0.160
Resistors, Composition	15	0.015	0.030
Resistors, W. W.	2	0.002	0.028
Capacitors, Paper	1	0.001	0.002
Capacitors, Tantalum	2	0.004	0.020
Capacitors, Mica	2	0.004	0.004
Subtotal		0.106	0.244
Video Amp.			
Transistors	9	0.180	0.390
Resistors	30	0.030	0.060
Capacitors, Paper	1	0.001	0.002
Capacitors, Mica	3	0.003	0.003
Capacitors, Tantalum	3	0.003	0.030
Diodes	4	0.040	0.160
Subtotal		0.257	0.645
Video Clamp Gen.			
Transistors	3	0.06	0.120
Resistors	10	0.01	0.020
Capacitors, Mica	2	0.002	0.002
Capacitors, Tantalum	2	0.002	0.020
Subtotal		0.074	0.162

Table IV.2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^5	
		@~ (-10°C to +10°C)	@~ (+40°C to +60°C)
Video Processor			
Transistors	5	0.10	0.200
Resistors	15	0.015	0.030
Potentiometer	1	0.15	0.150
Diodes	5	0.05	0.100
Capacitors, Tantalum	3	0.003	0.030
Capacitors, Mica	3	0.003	0.006
Subtotal		0.321	0.516
Light Sensor			
Photodiode	1	0.01	0.020
Transistors	2	0.04	0.080
Resistors, Composition	6	0.006	0.012
Resistors, W. W.	2	0.002	0.028
Subtotal		0.058	0.140
Iris Control			
Diodes	1	0.01	0.020
Potentiometers	2	0.30	0.150
Motor	1	1.00	1.500
Transistors	7	0.14	0.280
Resistors	18	0.018	0.036
Capacitors, Tantalum	1	0.001	0.010
Capacitors, Mica	1	0.001	0.001
Subtotal		1.470	1.997
Shutter Drive			
Transistors	6	0.12	0.240
Resistors	14	0.014	0.028
Diodes	2	0.02	0.040
Capacitors, Tantalum	2	0.002	0.020
Capacitors, Paper	2	0.002	0.004
Subtotal		0.158	0.332

Table IV.2-9

ASSEMBLY FAILURE RATES - TELEVISION SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} @ ~ (-10°C to +10°C)	Failure Rate in Failures Per Hour x 10^{-5} @ ~ (+40°C to +60°C)
Vidicon			
One inch, 0.6 watt filament - electromagnetic focus, electromagnetic deflection - λ =		2.00	4.50
Focus Coil and Yoke Assembly - Ruggedized, one piece		0.03 & 0.10	0.05 & 0.15
Vidicon Filament Supply			
Transistors	4	0.08	0.180
Diode	1	0.01	0.020
Resistors, Composition	10	0.01	0.020
Resistors, W. W.	1	0.001	0.014
Transformer, Toroid	1	0.125	0.150
Capacitors	2	0.002	0.020
Subtotal		0.228	0.404
Prepare-Read Gate			
Transistors	8	0.16	0.320
Resistors	24	0.024	0.048
Diodes	6	0.06	0.120
Subtotal		0.244	0.488
Clock and Command Control			
Transistors	64	1.28	1.050 1.720
Resistors	180	0.18	0.360
R. F. Choke	1	0.01	0.020
Capacitors, Mica	16	0.016	0.016
Capacitors, Tantalum	16	0.016	0.160
Capacitors, Paper	4	0.004	0.008
Diodes	18	0.18	0.360
Subtotal		1.686	3.694

Table IV.2-10

FAILURE RATE SUMMARY - TELEVISION SUBSYSTEM

Television Subsystem	Failure Rate in Failures Per Hour		Number of Times Per Earth Day Entering This State			Number of Times Per Lunar Day Entering This State			Times Per Earth Day In This State (Hours)			Times Per Lunar Day in This State (Hours)			P For One Lunar Day (14 Earth Days) -10 Days Operate	P For One Complete Lunar Day (28 Earth Days)	Notes
	-10°C to +10°C	+40°C to +60°C	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On			
Camera Clock and Sequencer	1.69×10^{6}	3.69×10^{6}	3	3	3	31	30	30	16.9	~6	1.1	236	~85	~15			
Vidicon Filament Supply	0.23×10^{6}	0.41×10^{6}	3	3	3	31	30	30	16.9	~6	1.1	236	~85	~15			
Light Sensor & Summer	0.06×10^{6}	0.14×10^{6}	3	3	3	31	30	30	16.9	~6	1.1	236	~85	~15			
Iris and Shutter Control	0.16×10^{6}	0.33×10^{6}	3	3	3	31	30	30	16.9	~6	1.1	236	~85	~15			
Subtotal	2.14×10^{6}	4.57×10^{6}	3	3	3	31	30	30	16.9	~6	1.1	236	~85	~15	0.9953	0.9951	
TV Camera Regulator	0.29×10^{6}	0.48×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Prepare-Read Gate	0.24×10^{6}	0.49×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Horizontal Blanking Gen.	0.28×10^{6}	0.42×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Blanking Mixer	0.06×10^{6}	0.11×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Read Sync Oscillator	0.08×10^{6}	0.17×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Vidicon Prepare-Read Gate	0.10×10^{6}	0.20×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Beam Current Reguator	0.22×10^{6}	0.31×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Horiz. Sync & Sweep Gen. & Amp Coil	0.58×10^{6}	0.94×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Horiz. Deflection Ampl.	0.12×10^{6}	0.36×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Divide by 2 TV Sync.	0.07×10^{6}	0.14×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Alignment Current Regulator	0.27×10^{6}	0.44×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
AGC Voltage Converter	0.26×10^{6}	0.71×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Shutter Drive	1.47×10^{6}	2.00×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Video Pre-amplifier	0.11×10^{6}	0.24×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Video Processor	0.32×10^{6}	0.52×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Video Amplifier	0.26×10^{6}	0.65×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Video Clamp	0.07×10^{6}	0.16×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			① This P is based upon the product of the operate and off reliabilities during the time intervals indicated. The operate reliabilities are as indicated while the off reliabilities reflect a failure rate of 1/100 of the operate levels.
Vertical Sweep Generator	0.30×10^{6}	0.51×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Vertical Defl. Ampl.	0.25×10^{6}	0.51×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Vert. Sweep Ampl. Control	0.11×10^{6}	0.22×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Alignment Coil	0.03×10^{6}	0.05×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
Deflection Yoke	0.10×10^{6}	0.12×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15			
TV Electronics Subtotal	8.54×10^{6}	9.75×10^{6}	$\sim1.23\times10^{3}$	NA	$\sim1.23\times10^{3}$	$\sim1.71\times10^{4}$	NA	$\sim1.71\times10^{4}$	22.9	NA	1.1	321	NA	15	0.9962 ①	0.9977 ①	
Vidicon	2.00×10^{6}	4.50×10^{6}	3	$\sim1.23\times10^{3}$	$\sim1.23\times10^{3}$	31	1.71x10	$\sim1.71\times10^{4}$	16.9	6	1.1	236	85	15	0.9953		
Azimuth Assy. Drive	0.80×10^{6}	1.00×10^{6}	44	NA	44	615	NA	615	Time is not a factor here; the probability of stepping the 615 steps is.						0.9990 ② (est)	0.9923	② This is an estimated value. The 615 steps is near the maximum and reflects generally a worst case. Also a failure here is not complete system failure even though it may occur early in the mission life.
Vidicon Face Plate Heater	0.15×10^{6}	0.15×10^{6}													0.9999	0.9988	
Iris Mechanics	Est. Mean Life 143,000 Operations		1.23×10^{3}	Oper./Earth Day (est)		17.1×10^{3} operations/lunar day (est)									0.9970 ③	0.9970 ③	
Shutter Mechanics	Est. Mean Life 143,000 Operations			Oper./Earth Day (est)		17.1×10^{3} operations/lunar day (est)									0.9970 ③	0.9970 ③	
Probability of complete TV subsystem operation for one half lunar day (14 E days) = 0.9617																	
Probability of TV Subsystem operation with some degradation loss of azimuth stepping = 0.9626																	③ The levels reflected here are based upon the data given in the attached memo.
Probability of complete TV subsystem operation for one Lunar day (28 E days) = 0.9790 ④																	④ Does not include long time low temp. vidicon storage reliability.

Table IV.2-11

ASSEMBLY FAILURE RATES - TELEMETRY SUBSYSTEM

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^5 From ~ 0°C to + 60°C
Axle No. 1 Components		
Transfer Register		
FF's	20	0.240
Gates	40	0.480
Subtotal		0.720
Timing and Program		
FF's	5	0.060
Gates	10	0.120
Subtotal		0.180
Analog Commutator		
Commutation Switches	20	
Transistors	20	0.400
Resistors	40	0.040
Diodes	80	0.800
Subtotal		1.240
Multiplexer		
Commutation Switches	2	0.124
Bootstrap Amplifiers	2	
Transistors	4	0.080
Diodes	4	0.040
Resistors	6	0.006
Level Shifters	10	
Transistors	10	0.200
Resistors	40	0.040
Diodes	20	0.200
Subtotal		0.690
Axle No. 1 Total		2.830

Table IV.2-11

ASSEMBLY FAILURE RATES - TELEMETRY SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} From ~ 0°C to + 60°C
Axle No. 2 Components		
Transfer Register		
Gates	200	2.400
Subtotal		2.400
Timing and Program		
FF's	30	0.360
Gates	40	0.480
Subtotal		0.840
Analog Commutator		
Commutation Switches	51	3.160
Subtotal		3.160
Multiplexer		
Commutation Switches	4	0.248
Bootstrap Amplifiers	4	0.252
Level Shifters	14	0.616
Subtotal		1.116
Total Axle No. 2 (Exclusive of CDP)		7.516
Analog to Digital Converter (CDP)		
FF's	10	0.120
Gates	30	0.360
Level Shifters	20	0.880
Transistors	20	0.400
Resistors (Precision)	11	0.154
Subtotal		1.914

Table IV.2-11

ASSEMBLY FAILURE RATES - TELEMETRY SUBSYSTEM (Continued)

Assembly and Component-Part Type	Part/ Module Qty.	Failure Rate in Failures Per Hour x 10^{-5} From ~0°C to + 60°C
Axle No. 2 Components (Cont'd)		
Frame Sync. Generator (CDP)		
Gates	33	0.396
Subtotal		0.396
Output Logic (CDP)		
Gates	4	0.048
FF's	12	0.144
Subtotal		0.192
Reference Supply (CDP)		
Diode (Zener)	1	0.040
Resistor	1	0.001
Subtotal		0.041
Oscillator (CDP)		
Transistors	4	0.080
Resistors	8	0.008
Capacitors	2	0.002
Crystal	1	0.010
Subtotal		0.100
Analog Comparator (CDP)		
Transistors	8	0.160
Resistors	14	0.014
Diodes	2	0.020
Subtotal		0.194
Subtotal (CDP)		2.837
Total Axle No. 2		10.353
Total Telemetry Subsystem		13.183

Table IV.2-12

FAILURE RATE SUMMARY - TELEMETRY SUBSYSTEM

Telemetry	Failure Rate in Failures Per Hour Approx. 10		Number of Times Per Earth Day Entering This State			Number of Times Per Lunar Day Entering This State			Times Per Earth Day In This State (Hours)			Times Per Lunar Day In This State (Hours)			P_s For One Lunar Day (14 Earth Days) -10 Days Operate	P_s For One Complete Lunar Day (28 Earth Days)	Notes
Subsystem	-10°C to +10°C	+40°C to +60°C	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On	Off	Std'by	On			
Axle No. 1																	The functions represented on Axle 1 and the portion of Axle 2 represented on this page are planned to utilize integrated circuits. The failure rate in the off state of these are assumed to be 10% of the estimated operate failure rate.
Transfer Register	0.720×10^{5}		< 3 > 2	1.23×10^{3}	<3> 2	31	1.71×10^{4}	30	~ 17	-1	~ 6	226	~ 15	~ 85			
Timing & Program	0.180×10^{5}		< 3 > 2	1.23×10^{3}	<3> 2	31	1.71×10^{4}	30	~ 17	-1	~ 6	226	~ 15	~ 85			
Analog Commutator	1.240×10^{5}		< 3 > 2	1.23×10^{3}	<3> 2	31	1.71×10^{4}	30	~ 17	-1	~ 6	226	~ 15	~ 85			
Multiplexer	0.690×10^{5}		< 3 > 2	1.23×10^{3}	<3 > 2	31	1.71×10^{4}	30	~ 17	-1	~ 6	226	~ 15	~ 85			
Subtotal Axle #1	2.830×10^{5}		< 3 > 2	1.23×10^{3}	<3 > 2	31	1.71×10^{4}	30	~ 17	-1	~ 6	226	~ 15	~ 85	0.9966	0.9965	
Axle No. 2																	
Transfer Register	2.400×10^{5}		< 3 > 2	1.23×10^{3}	<3> 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85			
Timing & Program	0.840×10^{5}		< 3 > 2	1.23×10^{3}	< 3 > 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85			
Analog Commutator	3.160×10^{5}		< 3 > 2	1.23×10^{3}	< 3 > 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85			
Multiplexer	1.116×10^{5}		< 3 > 2	1.23×10^{3}	< 3 > 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85			
Subtotal Axle #2 (Not including CDP)	7.516×10^{5}		< 3 > 2	1.23×10^{3}	<3> 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85	0.9908	0.9883	
Central Data Processor (CDP)																	
Analog to Digital Converter	1.914×10^{5}		< 3 > 2	1.23×10^{3}	< 3 > 2	31	1.71×10^{4}	30	~ 17	~ 1	~ 6	226	~ 15	~ 85			
Frame Sync. Gen.	0.396×10^{5}																
Output Logic	0.192×10^{5}																
Reference Supply	0.041×10^{5}																
Oscillator	0.100×10^{5}																
Analog Comparator	0.194×10^{5}																
Subtotal (CDP)	2.837×10^{5}														0.9966	0.9965	
Total Telemetry Subsystem	13.183×10^{5}														0.9840	0.9819	

Table IV. 2-13

ASSEMBLY FAILURE RATES - DIBSI

Item	Quantity	Operating Failure Rate ($X10^{-6}$hours)	Total Rate ($X10^{-6}$hours)
<u>Force Generator</u>			
Motor	1	1000[4]	1000.
Drive Train	1	20[1]	20.
Negator Spring	2	227[2]	454.
RF Filter	1	4	4.
Connections	12	.01	.12
		Subtotal	1478.12
<u>Instrument Ass'y.</u>			
Force Transducer	1	6.	6.
Acceleration Transducer	1	8.	8.
Temperature Transducer	1	2.	2.
Connections	12	.01	.12
		Subtotal	16.12
<u>Deployment Ass'y.</u>			
Motor	1	100.	100.
Drive Train	1	15.	15.
Bellows	1	10.	10.
Switch	2	3.	6.
RF Filter	1	2.	2.
Connections	18	.01	.18
		Subtotal	133.18
<u>Displacement Ass'y.</u>			
Potentiometer	1	10	10
Negator Spring	1	10[3]	10
		Subtotal	20

[1] Acceleration factor of 2
[2] Equivalent time rate at 100 strokes/minute
[3] Equivalent time rate at one extension per measurement.
[4] Acceleration factor of 10

Table IV.2-14

FAILURE RATE SUMMARY - DIBSI

Task: During a 10-day mission, 60 soil experiments must be completed. An experiment consists of one measurement with each of two tubes.

Work Profile: The operating profile for one measurement with one tube is:

Deployment	20 sec.
Soil Impact	120 sec.
Retract	30 sec.

Item	Operating Failure Rate ($X10^{-6}$ hours)[1]	Non-Operating Day Failure Rate ($X10^{-6}$ hours)	Operating Time 10-day Mission (hours)	Non-Operating Time 10-day Mission (hours)	P 10-day Mission	P 28-day Mission
Force Generator	1478[2]	14.78	2.0	222	.9966	.9916
Instrument Ass'y.	16	.16	2.0	222	> .9999	> .9999
Deployment Ass'y.	133	.1	.83	239.17	.9999	.9949
Displacement Ass'y.	20	.02	2.83	237.17	> .9999	> .9999
				Subtotal (one Tube)	.9963	.9863
				Total DIBSI	.9926	.9728

[1] Cycle or event sensitive equipment failure rates equated to equivalent time failure rate for the work profile.

[2] Internal environment of force generator required acceleration factors up to 10 on some part failure rates.

DIBSI can be considered redundant in the current two tube design, except for loss of scaling factor. The probability of survival of one DIBSI tube, giving all soil mechanics data except scaling factor is > .9999 for the 10-day mission, and .9993 for the 28 day mission.

Table IV. 2-15

ASSEMBLY FAILURE RATES - BASIC VEHICLE

Item	Quantity	Operating Failure Rate ($X10^{-6}$ hours)	Total Rate ($X10^{-6}$ hours)
Wheel Drive Ass'y.			
Motor	1	100.	100.
Drive Train	1	10.	10.
Bellows	1	10.	10.
External Bearings	3	5.[1]	15.
Clutch Mechanism	1	10.[1]	10.
RF Filter	1	2.	2.
Switch	1	1.	1.
Pressure Transducer	1	3.	3.
Temperature Transducer	1	2.	2.
Connections	20	.01	0.2
		Subtotal	153.2
Steering Ass'y.			
Motor	1	100.	100.
Drive Train	1	8.	8.
Bellows	1	5.	5.
RF Filter	1	2.	2.
Pressure Transducer	1	3.	3.
Temperature Transducer	1	2.	2.
Switch	5	1.	5.
Connections	24	.01	.24
		Subtotal	125.24
Thermal			
Thermal Switches	12	1.	12.
Isotope Pellets	3	Negligible	0.
		Subtotal	12.
Interconnect			
Leads	100	2.0[1]	200.
Connections	400	.01	4.0
		Subtotal	204.0
Clinometer	1	50[1]	50.
		Subtotal	50.

[1]Allocation

Table IV.2-16

FAILURE RATE SUMMARY - BASIC VEHICLE (including Clinometer)

Task: During a 10-day mission, travel approximately 27 km, perform 1700 steering steps, work about 110 hours.	Work Profile: Wheel Drive 31.6 hours; Steering 7.9; Thermal 240.0

Item	Operating Failure Rate ($X10^{-6}$ hours)	Non-Operating Day Failure[1] Rate ($X10^{-6}$ hours)	Operating Time 10-day Mission (hours)	Non-Operating Time 10-day Mission (hours)	P_3 10-day Mission	P_3 28-day Mission
Wheel Drive	918. (six units)	9.2	31.6	208.4	.9697	.9410
Steering Ass'y.	250. (two units)	2.5	7.9	232.1	.9975	.9875
Thermal	12.0[2]	-	240.	0.	.9972	.9851
Interconnect	204.0	2.	42.3[3]	197.7	.9914	.9612
				Subtotal	.9562	.8799
Clinometer	50.	.5	42.3[3]	197.7	.9974	.9974

[1] Non-operating failure rate assumed 0.1% of operating failure rate for mechanical and 1% for electronic.

[2] May be either time or cycle sensitive.

[3] Equivalent operating time = wheel drive + steering + DIBSI

Probability of survival of 5 out of 6 wheel drives for a 10-day mission is >.999 (using clutching)

Probability of survival of 4 out of 6 wheel drives for a 10-day mission is approximately 1 (using clutching)

Loss of mobility with one or two failed wheel drives is strongly influenced by terrain roughness. On very rough terrains, mission length may be significantly extended.

Probability of survival of 1 out of 2 steering mechanisms for a 10-day mission is .9999. Maneuverability is limited in rough terrain. Inclusion of self-centering device decreases effects of failure. (not contained in current design)

1b Lunar Night

The probability of the vehicle surviving lunar night is:

$$P_{night} = P_1 P_2 P_3 \cdots P_n$$

where

$P_1 P_2 \cdots P_n$ = the individual probabilities of portions of the SLRV surviving a lunar night.

To establish the probabilities in question requires a careful look at the equipment stresses expected during this period. During lunar night we can recognize only two deteriorating environments: low temperature and vacuum. The vehicle will have already been subjected to a number of earth days of the vacuum environment, and thus it would appear that the new environment, low temperature, would be the major source of failure.

As a basic ground rule, it has been assumed that there is no mechanical SLRV operation when the operating mechanisms are at a temperature of less than 0°F. This assumption removes all mechanical-functioning considerations at low temperatures and leaves only the question of sheet survivability. The figure of 0°F is somewhat arbitrary in nature, and at this point in the program has not been thoroughly pursued.

For lunar-night considerations, all SLRV equipment can be classified in two groups: thermally protected and non-thermally protected. The thermally protected equipment includes all items contained in vehicle compartments 1 and 2, the TV vidicon head, and the unique SLRV equipment in the basic bus compartment B. All other lunar SLRV equipment is considered to be non-thermally protected during lunar night.

The thermally protected equipments are primarily electronics. The prediction problem is to estimate the reliability of this equipment in a non-operating condition at temperatures down to 0°F.

A study effort was recently completed on a military system which contained electronics similar to the SLRV. This equipment had to survive long periods of storage at a temperature of approximately 5°C, and then operate upon command. The ambient pressure on the electronics was slightly greater than sea level. This study utilized work on failure-stress relationships and failure acceleration factors which had been performed by Eyering[(1)] and later by Battelle Memorial Institute. The conclusions reached from this study on the electronics' reliability during the dormant period were:

1. Reliability is a function of time.
2. The dormant failure rate is, on the average, a small fraction of the operating failure rate.
3. The failure distribution is probably normal in nature, at least during the positive slope period.
4. Reliability is an inverse function of storage temperature for the range considered.
5. An inert-gas or low-pressure environment would be desirable (Say 1" Hg.)
6. The basic failure mechanisms would be chemical-physical in nature.
7. The part-failure modes would be predominantly of a drift nature, often culminating catastrophically.
8. On the average, for all parts in the system, the peak in the failure distribution would be several years out.

[(1)] Currently, University of Utah

The similarity of the environments and types of electronic equipments of the above system and the SLRV suggests that the same conclusions may be valid for the SLRV electronics. The only area of significant difference is that the SLRV is in a hard-vacuum environment. Since all active electronic devices are hermetically sealed and all pressure-sensitive passive devices will, as a minimum, be near-hermetically sealed by encapsulation or other means, this is not felt to be a relevant factor.

The difference between a normal distribution and an exponential distribution is of little significance, since in both cases operation is in areas where the slope is very near zero.

The dormant-failure rates in the previously discussed program were in the general area of .02 to .002 of the operating-failure rate. One notable exception is the wet-slug tantalum capacitor, which has a higher dormant-failure rate than the operating-failure rate when the storage period approaches several months. The maximum SLRV dormant time is on the order of 14 - 18 Earth days, and this should present no problem. A storage-failure/operating-failure rate ratio of .01 has been selected for the SLRV temperature-controlled electronics. The .01 factor is similar to λ_3, covered earlier in this report.

The secondary-battery reliability has been predicted at the same failure rate as that of lunar-day operation.

The non-thermally-protected equipments include the vehicle structure, external cabling, antenna, solar panel, wheel drives, steering assemblies and DIBSL The previously stated ground rule of "no mechanical operation or movement at low temperatures" simplifies the prediction problem, since it is not necessary to consider the effects of dynamic loading on materials at very low temperatures. All equipment will be attempting to survive lunar night in a static mode. It should be noted that the non-thermally protected equipment is primarily mechanical in nature.

There are two sources of failure to consider for this equipment in addition to the vacuum condition.

a. Failures resulting from approximately 14-18 days of dormancy, and

b. Failures resulting from being subjected to lunar-night ambient temperatures (-250°F).

The first of these, dormancy, can be predicted by conventional means. The ratio of non-operating/operating failure rates for mechanical devices as a function of time appears to vary widely. A value of .001 has been used on other programs for rotating components such as motors and gear trains, and is the value used for λ_3 earlier in this report. Applying this value gives a probability of lunar survival for the non-thermally controlled equipments, recognizing only dormancy-induced failures, of .9988.

Equipment failures resulting from the second of the failure sources, low temperature, will be cycle-sensitive rather than time-sensitive, as in the case of the thermally protected equipment. That is to say, the equipment probability of failure will be a function of the number of cycles of low temperature to which it is subjected, not a function of the amount of time spent at low temperature.

No known data is available to establish numerical failure rates for this equipment. Therefore, it was necessary to use engineering judgment to establish allocations for the probability of survival of this equipment.

The predicted primary source of failure is the motor and gear-train assemblies used for various functions on the vehicle. The need for retaining pressurization and the extremely wide range of temperatures which the mechanisms must withstand (approximately 600°F) indicate numerous possible sources of failure, when cycled to -250°F. An allocated probability of survival, .995, has been assigned to each of the motor gear-train assemblies. Should this number in fact be optimistic, an R&D program of the nature anticipated for the SLRV should be able to so identify it within engineering judgment, and possibly with an acceptable degree of statistical significance.

The solar panel, which was anticipated to be a major source of lunar-night failure earlier in the SLRV program, does not now appear to be a major risk. With the qualification of the Surveyor array, it has been established that an array can survive the low temperature. Also, using an array configuration which has a number of parallel solar-cell strings with diode isolation, results in a primary failure mode of only partial loss of array power output, which should not be catastrophic on the mission.

Qualification testing of the SLRV vehicle to the anticipated lunar-night environment will permit a high degree of confidence in the adequacy of the basic design. Further, it is anticipated that normal production testing of the flight hardware will include several cycles of low temperature to assure the individual integrity of the equipment.

Table IV.2-17 is a summation of SLRV equipment failures for one lunar night, utilizing the expression for P_{night}.

2 Surveyor Bus

The SLRV indirect-communications configuration requires inclusion of the Surveyor bus as part of the SLRV system for the lunar operating phase. In accordance with JPL responses to questions regarding bus reliability (letters dated 13 and 31 December 1963, H. Davis of JPL to R. Kieding of GMDRL), the existing Surveyor Spacecraft reliability requirements are being utilized. These requirements do not include the scientific-instrument and scientific-instrument-support subsystems, resulting in a model configuration which should be representative of the Surveyor bus.

Table IV.2-17

SUMMATION OF SLRV EQUIPMENT FAILURES FOR ONE LUNAR NIGHT

Item	Thermal Protection Yes	Thermal Protection No	Prediction Method	Prob. of Night Survival
Compartment 1 & 2 & B equipment (except battery)	X		A	.996
TV Head	X		B	.990
Battery	X		A	.993
Thermal Subsystem	-	-	A	.988
Cabling & Structures		X	B	.980
Motors & Gear Trains (13)		X	C	.937
Antennas, Solar Panel, Misc.		X	B	.990
			P_{night} =	.879

Prediction Method:

A - Calculation

B - Allocation based on engineering judgment

C - Allocation based on engineering judgment which if optimistic should be identifiable in R&D test program.

During the lunar operating phase after landing, the Surveyor Spacecraft has two reliability requirements.

a. .95 probability of completing the first 80 hours of lunar operation, and

b. .75 probability of completing the first 504[1] hours of lunar operation.

To be applied in the SLRV lunar-phase prediction format, these requirements must be transformed into an equivalent-lunar-day failure rate and a lunar-night probability of survival.

Reliability modeling data on the Surveyor Spacecraft generated by Hughes Aircraft Company was forwarded to GMDRL by JPL. This data was studied in an attempt to convert the Surveyor requirements into the desired form.

(1) Verbal information form JPL Reliability indicates this has been reduced to 21 days from 30 days.

This was not directly possible because of differences in the Surveyor mission model and in the SLRV mission model. The HAC data indicates that the Surveyor operating model is essentially nonrepetitive in nature, which appears logical considering the number and nature of experiments involved. The SLRV mission model, however, is very repetitive in the modeled mission strategy. Therefore, it has become necessary to identify an average lunar-day failure rate based on the 80-hour requirement presuming an exponential failure distribution (telecon J. Shear JPL, H. Fue GMDRL 2/13/64). This average failure rate can be derived through use of the expression:

$$\lambda = -\frac{\ln (Ps)}{t}$$

where

λ = Surveyor lunar day failure rate.

P_S = .95

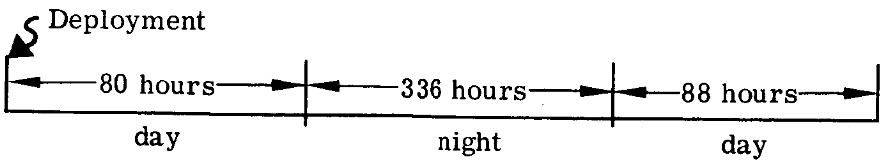
t = 80 hours

Substituting gives a failure rate of 642×10^{-6} failures per hour. This failure rate has been used for all computations of Surveyor basic bus lunar-day operation in support of an SLRV mission.

The SLRV reliability model has recognized the lunar-night portion of the mission as essentially an event, with very little consideration of the time involved. In the HAC model, however, it appears that several subsystems are energized during portions of the lunar night, and HAC has elected to consider a time model.

Since we have established a lunar-day average failure rate, and we know that the 80 hour requirement applies to the end of a lunar-day[1], it is possible to establish a possible work-day profile:

[1] HAC briefing to SLRV contractors, 10/24/63



(80 + 336 + 88 hours = 21 days)

From the HAC reliability-model data, the Surveyor night period is evidently shorter than that proposed for the SLRV.

Using the above profile we can then establish the probability of Surveyor lunar-night survival:

$$P_n = \frac{P_{504}}{P_{80} \exp(-88\lambda_d)}$$

where

P_n = Probability of lunar-night survival

P_{504} = Probability of 504 hour survival (.75)

P_{80} = Probability of first 80 hours survival (.95)

λ_d = Average lunar-day failure rate (642×10^{-6})

Solving, $P_n = .835$. This value is used for the Surveyor bus probability of lunar-night survival in support of an SLRV mission. The derivation of the Surveyor bus reliability numbers for the SLRV mission is less vigorous than might be desired, but it is believed to be reasonable accurate.

3 Mission Probability of Success

Table IV. 2-18 lists the computed probabilities of success for each subsystem of the SLRV.

Table IV. 2-18 summarizes the predicted mission probability of success for the SLRV, the basic bus, and the total system for lunar operating phases of 10 Earth-days and 28 Earth-days duration. The 10 Earth-day mission is that associated with the Standard Reliability Mission. The 28 Earth-day mission is 10 Earth-days of lunar survey, and the remainder lunar night. It is presumed that there is an average of 10 Earth-days of SLRV work time in a lunar day.

Table IV. 2-18

SLRV PROBABILITY OF MISSION SUCCESS AFTER DEPLOYMENT

	10 Earth-Days	28 Earth-Days
SLRV	.857	.757
Surveyor Basic Bus	.871	.727
TOTAL	.746	.550

The predicted probability of success for the SLRV and for the SLRV with the basic bus is depicted in Figure IV. 2-2 as a function of time after deployment. The abscissa is scaled in total earth-work-days after deployment and in total calendar-earth-days after deployment. The rate of failure shown is that associated with the standard reliability mission. The discontinuity in the curves represents the effects of lunar night. During lunar night, while considerable reliability risk is accrued, no useful work is accomplished. The desirability is obvious of an early-daylight landing and a mission strategy to accomplish the desired major objectives prior to lunar night.

Figure IV. 2-3 plots mission probability of success as a function of smooth-area percentage for the SLRV and for the SLRV and basic bus. The source data for time of mission is derived from recent missions-analysis studies and is not in exact agreement with the Standard Reliability Mission. The failure rate used, however, is that associated with the Standard Reliability Mission. The discontinuity in the curves is the point at which the mission time exceeds 10 Earth days. It should be noted that this graph presents mission probability of success from an equipment reliability point of view only, and does not include consideration of the probability of certifiability of very small smooth-area percentages. For very large smooth-area percentages, the mission search strategy of the Standard Reliability Mission may not be valid.

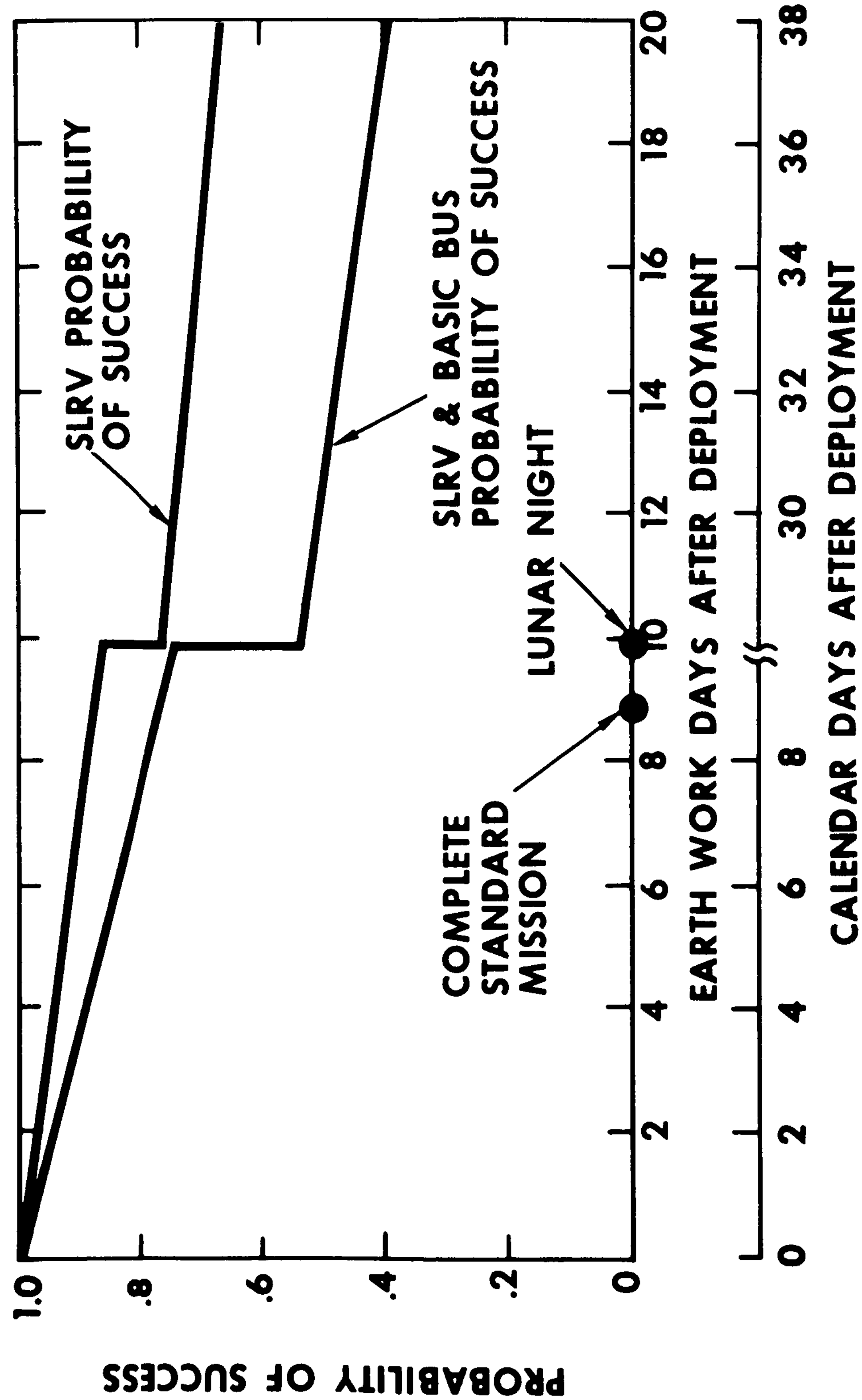


Figure IV.2-2 SLRV System Reliability vs Time for Reliability Standard Mission

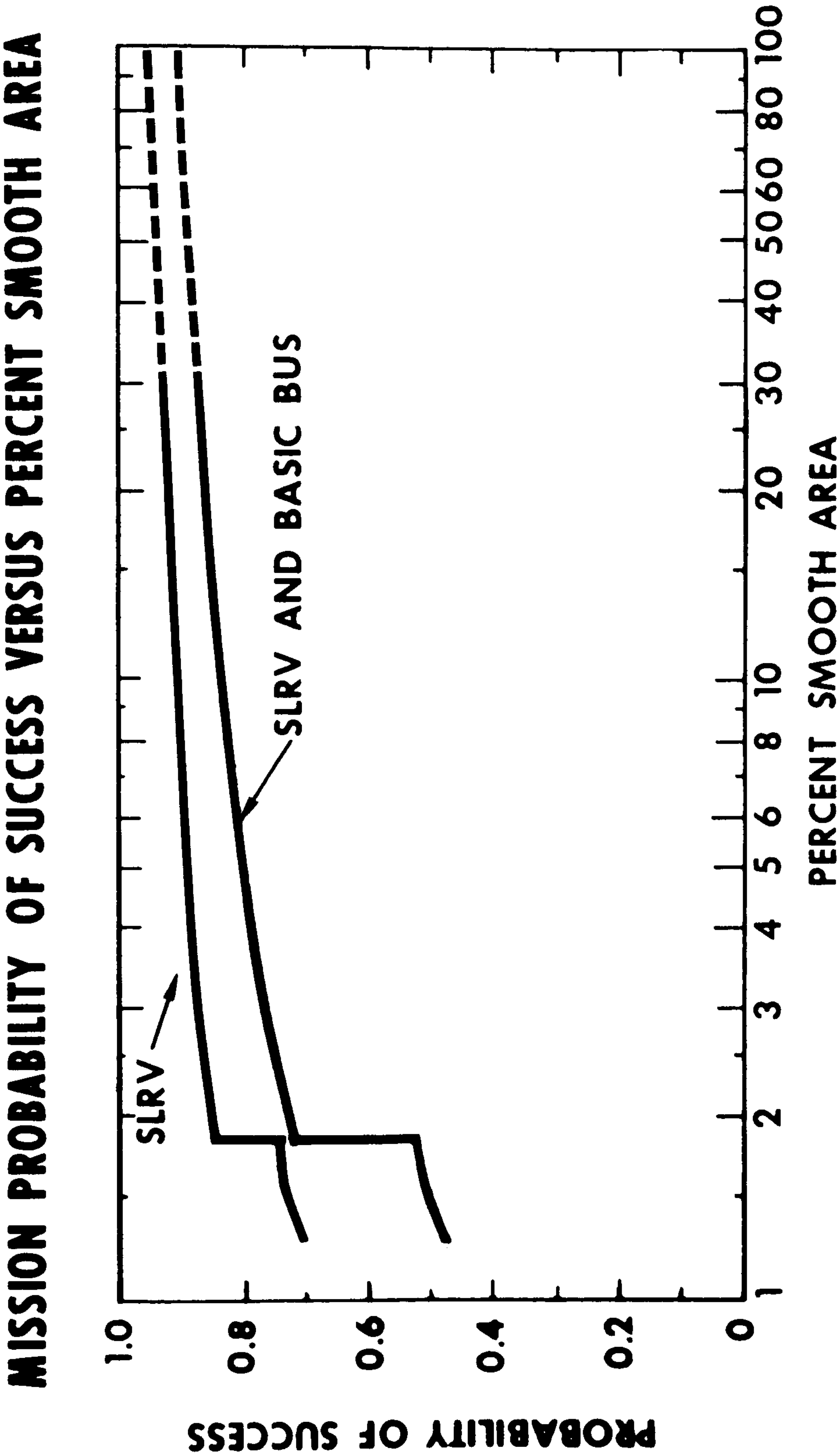


Figure IV.2-3 Mission Probability of Success vs Percent Smooth Area
(Survey Phase)

APPENDIX III

FAILURE MODE AND EFFECTS ANALYSIS

Analyses have been completed identifying the predicted failure modes on all subsystems of the SLRV flight hardware. The system configuration examined is shown in Figure IV.2-1; it is based on the current 100-pound system configuration. Figure IV.3-1 is a simplified functional block diagram of the electronics subsystem examined.

The analyses examined the best candidate of the available preliminary designs on each subsystem. The amount of detailed design data varies on the different subsystems and as such the analysis effort reflects varying degrees of detail.

Tables IV.3-1 through IV.3-8 present the analyses and are as follows:

Table IV.3-1	Failure Mode and Effects Analysis - Power Supply Subsystem
Table IV.3-2	Failure Mode and Effects Analysis - Command & Control
Table IV.3-3	Failure Mode and Effects Analysis - Television Subsystem
Table IV.3-4	Failure Mode and Effects Analysis - Communications Subsystem
Table IV.3-5	Failure Mode and Effects Analysis - Telemetry Subsystem
Table IV.3-6	Failure Mode and Effects Analysis - DIBSI Subsystem
Table IV.3-7	Failure Mode and Effects Analysis - Basic Vehicle Subsystem
Table IV.3-8	Summary - Major Failure Modes and Effects Analysis for SLRV

The following column heading definitions are used for the tables:

Item and Title - The equipment, usually at the assembly level or lower, which has failed.

Assumed Failure - Brief description of failure.

Possible Causes - Self explanatory.

Symptoms and Local Effects - Evidence of malfunction and its effect on companion equipment.

Compensating Provisions - Conditions or methods by which the effect of the failure can be reduced or eliminated.

Effect of Mission - Self Explanatory.

Failure Class - The seriousness of the failure in preventing accomplishment of the mission objectives. Failure class factors were ranked into categories of importance as follows:

1. Catastropic data or System loss;
2. Critical data loss;
3. Major data loss;
4. Minor data loss;
5. Negligible data loss.

Failure Probability - Rated on an arbitrary scale of decreasing probability, 1 through 5.

Remarks - Self-explanatory.

Many of the failure modes can be degraded in seriousness or eliminated by adding additional equipment or remechanizing. The majority of these changes can be accomplished only with additional weight. The system weight goal of 100-pounds is currently used to provide the system configuration analyzed. The probability of reducing the existing systems weight, to allow for significant reliability improvement, without compromising mission objectives, is not encouraging.

As a part of the Phase I study program, weight configurations up to 150 pounds were examined, to identify increases in SLRV performance which could be obtained. The failure mode and effects analysis results were used extensively in generating the increased weight budgets.

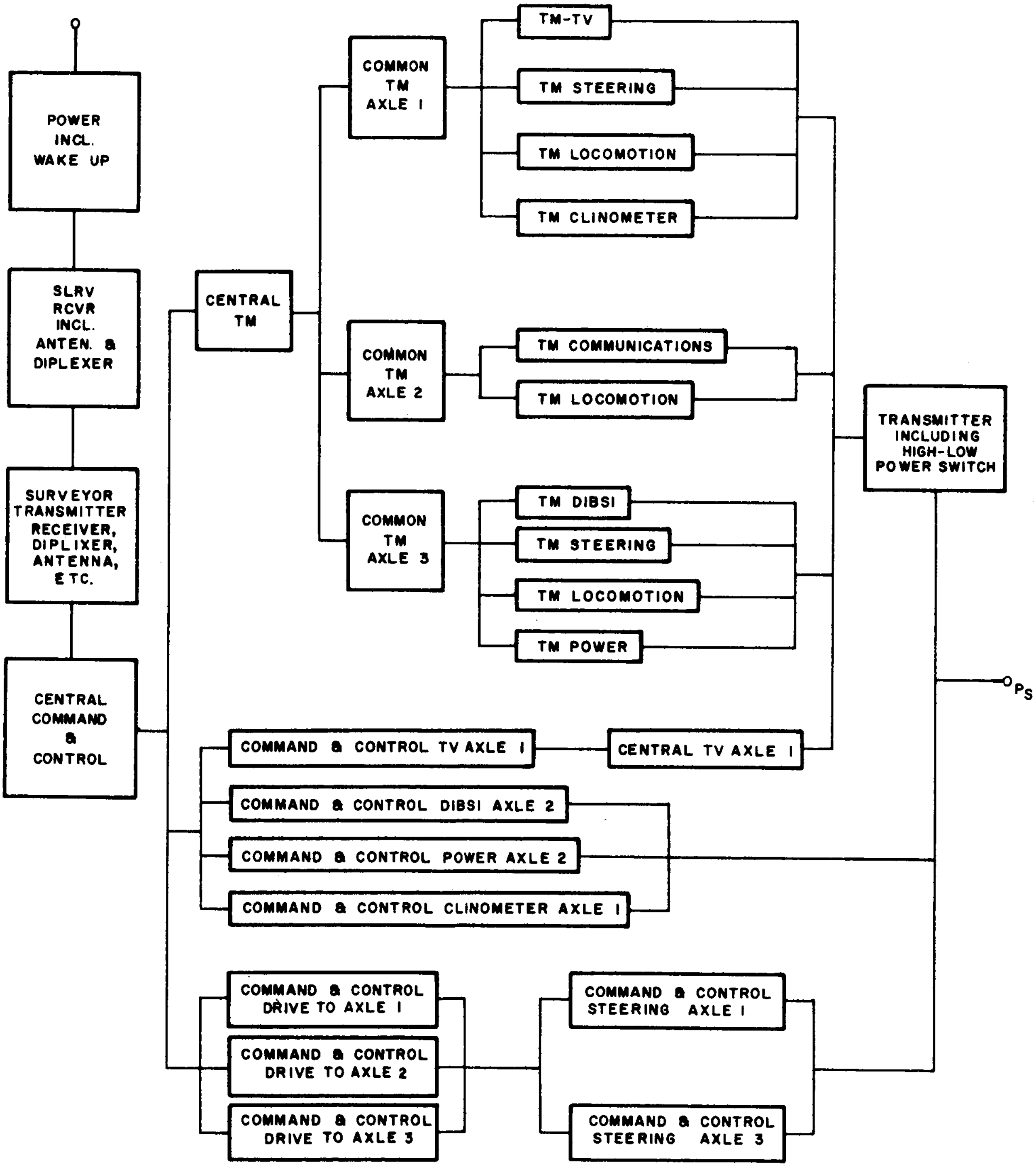


Figure IV.3-1 Vehicle Electronics Subsystems Functional Block Diagram

Table IV.3-1

FAILURE MODE AND EFFECTS ANALYSIS LUNAR ROVER FOR POWER SUPPLY SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV System	Failure Class	Failure Probability	Remarks
Solar Array	Shorted Cell(s)	Mechanical & thermal stress and/or shock	Degradation of output power & voltage	Overcapacity & string isolation	Degradation of battery charging capabilities	3	3-4	Provide overcapacity to compensate for failures and degradation.
	Open Cell(s)	Mechanical & thermal stress and/or shock	Degradation of output power & voltage	Overcapacity & string isolation	Degradation of battery charging capabilities	4	2-3	Provide overcapacity to compensate for failures and degradation.
	No array output	Mechanical & thermal stress and/or shock, plus failed cabling, connections, etc.	Loss of charging capabilities	None	Available power limited to charge of battery	1	5	Use best cable & connectors available. Redundant output cables and connectors.
Converter	No output	1) Failed power transistors in converter chopper stage. 2) Failed Rectifier Assemblies 3) Failed Transistors	No standby operating mode capability	None	Loss of all System Command and Control Capability	1	5	
	Partial Output	Failed rectifier assembly	Loss of some standby operating-mode capability	None	Loss of most or all system Command and Control Capability	1	5	
State-of-Charge Monitor	Loss of State-of-charge data	1) Failed magnetic amplifiers 2) Failed counting or associated current level sampling circuitry	Loss of telemetry data on charge state Loss of telemetry data on charge state	None None	Battery state cannot be ascertained	2	4	These failures are critical even though they do not immediately cause system failure. Some operation is still possible after a failure providing batteries are not below their minimum charge level. Also, operation is still possible if a power profile has been derived and can still be applied.
Battery		Short life battery	Degradation of output power & voltage	None	Loss of peak power capabilities no output during lunar night or lunar shadows	2	3-5	Provide maximum battery capacity allowable.
Hibernation Circuit	No wake up signal	Failure to sense wake-up time	No turn-on input to voltage regulator	None	Complete loss of power and system	1	3	Hibernation device should be redundant in an either-or configuration.
	No hibernation	Hibernate switch does not disconnect battery from load	Continuous power drain during lunar night	None	No available power after 1st designated hibernation period	3	3	
Voltage Regulator	No output	Open series regulator or regulator driven hard off	No available power to subsystems	None	Complete loss of power to all SLRV functions	1	4-5	Solar array may supply power for command & control and telemetry data.
	Loss of regulation	Regulator fails in hard on state	Peak solar array and battery power applied to loads	Some internal subsystem regulation-batteries will tend to smooth output voltage characteristic	Some voltage sensitive circuits affected but most operations still possible	4	3	Telemetry data can supply best operate time from battery voltage state.
Power Subsystem Telemetry	State of charge data	State of charge failure	Loss of telemetry data	None	Battery state difficult to ascertain-mission compromised	2	4	
	Battery temperature data	Sensor failure	Loss of telemetry data	None	Battery state difficult to ascertain-mission compromised	3	5	
	Other data loss	Sensor failure	Loss of telemetry data	None	Minor	4	5	

TABLE IV.3-2

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Clear Command	Loss of	Failed Clearing Electronics	Loss of emergency stop, error override, emergency stop override, and clearing of steering inhibit	Individual commands to reset associated flip-flops	Some operational delay in determining which flip-flops need to be individually reset	4	5	Equipment operation can still continue after clear command has been given.
	Continuously on	Failed Clearing Electronics	Continuous reset commands to error, emergency steering inhibit, disconnect, override, and locomotion, steering and DIBSI motors stop	None	Loss of locomotion, steering and DIBSI motors	2	5	TV pictures and telemetry still available but this is restricted to a fixed point observation since no mobility exists.
XMTR High Pwr. on Command	Loss of	Failed TV power on electronics	No high power TV capability, but low power still possible	No highpower TV but low power capability still exists	Operation of vehicle	4	5	Extreme caution needed to keep vehicle out of deep RF nulls.
	Continuously on	Failed TV power on electronics	Continuous high power TV operation during TV mode	None	Excess power drain and vehicle life shortened	3	5	
TV Standby Command	Loss of	Failed TV power standby electronics	TV in off state	None	Operation sequence and power consumption	3	5	The system goes from full off to full on. No standby (warm) capability. TV operate program will have to be altered to fit this failure mechanism.
	Continuously on	Failed TV power standby electronics	TV in standby continuously	VSD turn off or power charge mode as partial compensation	VSD turn off required to shut down TV system	3	5	TV operate is an independent and separate chain of commands.
TV Power Off Command	Loss of	Failed TV power off electronics	No TV power off capability	VSD's off or power charge mode	Power consumption high and mission shortened	3	5	
	Continuously on	Failed TV power off electronics	TV stays off	None	No TV capability	1	5	
TV Azimuth Head Step CW Command	Loss of	TV Azimuth head step CW electronic failures	No CW Azimuth head stepping	CCW stepping	Increased power consumption and mission time extended	4	5	

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
TV Azimuth Head Step CW Command (Continued)	Continuously on	TV Azimuth head step CW electronic failures	Azimuth head stepping pulses lost	Turn azimuth head VSD off	Loss of stepping in CW direction	3	5	
TV Azimuth Head Step CCW Command	SAME AS TV AZIMUTH HEAD STEP CW					4 3	5 5	
Take TV Picture Command	Loss of	Failure of take TV Picture Electronics	No TV	None	No TV for guidance or mapping	1	5	
	Continuously on		TV pictures taken when not commanded	TV Power off through turn off of VSD	Mission life degraded and DIBSI data sacrificed	3	5	Separate VSD off commands and TV operate and DIBSI on different VSD's.
TV Height Step Command	Loss of	Failure of TV height head step electronics	No TV height stepping	None, other azimuth stepping and vehicle reorientation	Mobility and navigability of SLRV due limited vision	3		
	Continuously on	Failure of TV height head step electronics	Height stepping pulses lost	TV Power off through VSD deactivate or power charge mode	Some loss of data, primarily DIBSI, and mission time extended	3	5	
Power Charge Command	Loss of	Failure of Power charge command electronics	Vehicle power cannot be switched into power charge from operate, standby or hibernate modes	Individual commands can shut down all but command sequence of VCD	Mission life shortened	2	5	
	Continuously on	Failure of Power charge command electronics	Vehicle power cannot be switched out of charge mode	Operate equipment at maximum allowable dissipation to keep batteries from being overcharged; however during hibernate this is not possible	Mission abort would occur during high noon hibernate	2	5	
Hibernate Alert Command	Loss of	Failure of hibernate alert command electronics	Vehicle cannot be placed in complete hibernation	Command power off to all subsystem except command subsystem	Vehicle survivability during hibernation period	2	5	Not critical if mission is near complete, at high noon hibernate the loss is high.

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Hibernate Alert Command (Continued)	Continuously on	Failure of hibernate alert command electronics	None, if hibernate execute is not triggered	Hibernate execute	None	4	5	Not critical
Hibernate Execute Command	Loss of	Failure of hibernate execute command electronics	Vehicle cannot be placed into complete hibernation	Partial compensation by individual subsystem shut down capability	Mission life	2	5	Same as loss of hibernate alert command above.
	Continuously on	Failure of hibernate execute command electronics	None, without hibernate alert	Hibernate alert	None	4	5	Not critical
Telemetry Off Command	Loss of	Failure of Telemetry Off Command Electronics	TM data at inappropriate times	None	Interference with video transmission	3-4	5	
	Continuously on		SAME LOSS OF TM ON COMMAND ABOVE			2	5	Same as loss of TM on command above.
VSD's On Command	Loss of	Failure of VCD or VSD to turn on	No subsystem command capability	None	Mission abort	1	5	Redundancy should be used where possible.
	Continuously on	Failure of VCD or VSD to turn off	Normally none, except VSD's cannot be turned off except by hibernate execute or power charge if failure is in VSD	Hibernate execute or power charge	Mission life shortened by higher power drain	3	5	
VSD's Off Command	Loss of	Failure of VCD or VSD to respond to VSD off command	SAME AS VSD "CONTINUOUSLY ON"		Same as above	3	5	
	Continuously on	Failure of VCD or VSD to turn off	SAME AS VSD "LOSS OF COMMAND"		Mission abort	1	5	Same as loss of VSD off command.
Error Override Command	Loss of	Failed instruction error reset command electronics	Single error command cannot be corrected	Possible use of clear to reset. Complete vehicle	Loss of some operating time	3	5	
	Continuously on	Failed instruction error reset command electronics	All commands correct or not are reset	None	Vehicle immobilized	1	5	

TABLE IV. 3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Emergency Stop Override Command	Loss of	Failed emergency stop override command electronics	No override of vehicle motion commands	Vehicle clear or power to charge or hibernate commands	Loss of operational time if failure is detected prior to vehicle self inflicted damage	3	5	
	Continuously on	Failed emergency stop override command electronics	Continuous override command received	None	Vehicle remains immobilized	2	5	
DIBSI Select Command	Loss of	Failed DIBSI select command electronics	DIBSI cannot be activated	None	DIBSI data lost	2	5	
	Continuously on	Failed DIBSI select command electronics	DIBSI select activated without command	None	DIBSI data limited to one DIBSI source	3	5	
XMTR High Power Select Command	Loss of	Failure of XMTR high power command electronics	No high power TV capability	Vehicle low power TV operation	Mapping capability and TV resolution limited by lunar terrain	3	5	Vehicle must stay out of deep nulls. RCV'R AVC signal should be telemetered for indication.
	Continuously on	Failure of XMTR high power command electronics	High power mode cannot be switched off	XMTR high power turn off through power charge	Reduce mission time resulting from XMTR power drain	3	5	
XMTR Low Power Command	Loss of	Failure of XMTR low power command electronics	No low power capability	High power operation	Operate time reduced	3	5	
	Continuously on	Failure of XMTR low power command electronics	Transmitter cannot be turned off	Power charge or hibernate will turn transmitter off	Operate time reduced	3	5	
XMTR off Command	Loss of	Failure of XMTR off command	XMTR stays on	Power charge or hibernate mode will turn XMTR off	Mission life shortened	3	5	
	Continuously on	Failure of XMTR off command	XMTR stays off	No TV, wideband or narrow band	Mission abort	1	5	
Range and Bearing on Command	Loss of	Failure of range and bearing command on electronics	No range and bearing data	None	Precision of mapping	3	5	
	Continuously on	Failure of range and bearing command on electronics	Superfluous range and bearing inputs	None	Mission life	3	5	

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Telemetry on Command	Loss of	Failure of Telemetry on command electronics	No telemetry data	None	Loss of major portion of mission data	2	5	Telemetry data is essential to mission performance, redundant command capability should be utilized to insure its acquisition.
	Continuously on	Failure of Telemetry on command electronics	TM data at inappropriate times	None	Interference with video transmission	4	5	
Operate Mode Command	Loss of	Failed electronics or switching to operate mode	If in charge mode prior to this command, vehicle remains in charge unless route through TV mode is open	Individual command set-up capability or mode rerouting	Mission time increased if mode can be reached by other paths; a complete loss if it cannot	1-3	3	If the vehicle can be routed into this state by an individual command means or other modal routes the failure class is only major. If not, it is catastrophic. Rerouting or the individual command capability should be assured not locked out by either of these two failure modes.
	Continuously on	Failed electronics or switching to operate mode	TV in standby, all other subsystems in normal operation	Individual command capability to change equipment states	Same as above	1-3	3	
TV Mode Command	Loss of	Failure of TV mode command electronics	No power to TV subsystem beyond operate (standby) levels	None	Navigation and mapping function of SLRV	1	5	This command channel should incorporate redundancy since its importance is so high.
	Continuously on	Failure of TV mode command electronics	Continuous power to TV subsystem electronics	VSD's off or system to power charge mode	Loss of some other data	2	5	
DIBSI Deploy Command	Loss of	Failure of DIBSI deployment command electronics	No power to DIBSI deploy mechanisms	None	Loss of DIBSI data	2	5	
	Continuously on	Failure of DIBSI deployment command electronics	Continuous power to DIBSI deploy mechanisms	VSD's to off state by command or system to power charge	Loss of TV if DIBSI cannot be cleared	1	5	Provide safety cutout at completion of deployment excursion.
DIBSI Retract Command	Loss of	Failure of DIBSI retract electronics	DIBSI remains extended	None	Mission abort	1	5	
	Continuously on	Failure of DIBSI retract electronics	DIBSI retract signal stays on	None	Power drain excessive	1	5	Provide safety cut out at completion of retract cycle.

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
DIBSI Start Command	Loss of	Failure of DIBSI start sequence electronics	No DIBSI	None	No DIBSI data	2	5	
	Continuously on	Failure of DIBSI start sequence electronics	DIBSI receives continuous operate signal	DIBSI stop command	DIBSI stop release will allow start to commence again	1	5	Start command should be time limited so that if it fails on it will not bring the rest of the system down.
DIBSI Stop Command	Loss of	DIBSI stop command electronics failure	DIBSI start command motor receives power continously	None, except power charge	Complete system	1	5	
	Continuously on	DIBSI stop command electronics failure	No DIBSI start	None	Loss of DIBSI data	2	5	
TV Sun Sensor Override Command	Loss of	Failure of sun sensor override electronics	TV picture either over or under exposed	None	TV presentation	2	5	The need for this is indeterminate as the requirement for override is not known precisely.
	Continuously on	Failure of sun sensor override electronics	TV picture either over or under exposed	None	TV presentation	2	5	
Pellet Heating on Command	Loss of	Failure of pellet heating command electronics	No pellet heating when required	None	Probable, survivability during lunar night	3	5	
	Continuously on	Failure of pellet heating command electronics	Pellet heating when not required	Subsystems turned off to prevent overheating	Extremely limited operation	2	5	
Pellet Heating off Command	Loss of	Failure of pellet heating off command electronics	None, until heating is to be discontinued, then overheating occurs	None	Continuation of SLRV mission	3	5	
	Continuously on	Failure of pellet heating off command electronics	No pellet heating when required	None	Lunar night survivability	3	5	
Locomotion Forward Command	Loss of	Failed electronics associated with locomotion forward command	No forward locomotion on command	Back-up and rearward looking azimuth position of camera give continued TV capability	Degraded locomotion capability and possible degraded TV navigation capability (if TV mast in rearward viewing presents a significant viewing obstruction)	3	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.

TABLE IV. 3-2 (Continued)

FAILURE-MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Locomotion Forward Command (Continued)	Continuously on	Failed electronics associated with locomotion forward command	Forward locomotion in the absence of command	Wheel disengage commands to offending wheels or possible reverse locomotion command if connection configuration allows this	Battery life limited by excessive power drain and TV blurred by vehicle motion during exposure interval	3	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
Locomotion Reverse Command	Loss of	Failed electronics associated with locomotion reverse command	No reverse locomotion on command	Turning and steering capability	Degraded locomotion capability	3	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
	Continuously on	Failed electronics associated with locomotion reverse command	Reverse locomotion in the absence of command	Wheel disengage commands to offending wheels or possible forward locomotion command if connection configuration allows this	Battery life limited by excessive power drain and TV blurred by vehicle motion during exposure interval	3	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
Steer Center Command	Loss of	Failed electronics associated with steer center command	Vehicle cannot be steered "Dead Ahead" after a turn to right or left	Step right or left and step hard right or left can accomplish some "Dead Ahead" maneuvering in terms of resultant path traversed	Degraded performance due to loss of some directional control	4	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
	Continuously on	Failed electronics associated with steer center command	Vehicle cannot be steered right or left	None	Loss of mobility-steering can only be accomplished by front or rear wheel disengaging and allowing drag of free wheeling	4	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
Steer Step Right Command	Loss of	Failed electronics associated with steer step right command	Vehicle cannot be steered a step right maneuver by single command	Steer hard right in combination with steer center can be used to accomplish same directional control	Some decreased mobility and time and power loss to accomplish step right	4	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
	Continuously on	Failed electronics associated with steer step right command	Vehicle receives continuous step right command	None		1-3	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Steer Step Left Command	Loss of Continuously on			BASICALLY, THE SAME AS STEER STEP RIGHT COMMAND				
Steer Hard Right Command	Loss of	Same as above except steer hard right electronics	No hard right control	None	Vehicle navigability restricted	4	5	The failures associated with each of these commands alone is not sufficient to cause a mission abort or failure.
	Continuously on		Continuous hard right in the absence of command	None	Effective mission near termination at this point if this failure occurs	1-2	5	
Steer Hard Left Command	Loss of Continuously on			BASICALLY, THE SAME AS STEER STEP RIGHT COMMAND				
Wheel Disconnect Execute	Loss of	Failed wheel disconnect execute electronics	None, if wheel disconnect is not required. If wheel disconnect is required then the wheel desired to be disconnected presents locomotion and steering problems	None	Vehicle mobility and navigability limited if disconnect is required	3	5	
	Continuously on	Failed wheel disconnect execute electronics	None, if wheel disconnect is not required. If wheel disconnect is required than the wheel disconnect alert will operate wheel disconnect	Wheel disconnect alert	None, if no other failures, particularly wheel disconnect alert occur	5	5	
Wheel Disconnect Front Right Alert	Loss of	Failed wheel disconnect front right alert electronics	None, if wheel disconnect is not required. However, if disconnect of wheel is required it can not be accomplished	None	Vehicle mobility and navigability limited if disconnect is required	3	5	
	Continuously on	Failed wheel disconnect front right alert electronics	None, if wheel disconnect is required of this or any other wheel. However, this wheel will be disconnected needlessly if the execute command is transmitted	Wheel disconnect execute	Vehicle mobility and navigability is limited if disconnect is required	3	5	

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Wheel Dis-connect Front Left Alert Wheel Dis-connect Rear Right Alert Wheel Dis-connect Rear Left Alert	Loss of Continuously on	BASICALLY, THE SAME AS WHEEL DISCONNECT FRONT RIGHT ALERT						
Wheel Dis-engage Center Right Command	Loss of	Failed electronics as-sociated with wheel dis-engage center right command	Degraded mobility if needed, none if not	None	Vehicle mobility	3	5	
	Continuously on	Failed electronics as-sociated with wheel dis-engage center right command	None, if disconnect execute is not given If wheel disconnect is given this wheel is disconnected	None Wheels engage center command	 Vehicle mobility	3 3	5 5	
Wheel Dis-engage Center Left Command	Loss of Continuously on	BASICALLY, THE SAME AS WHEEL DISENGAGE CENTER RIGHT COMMAND						
Wheels Engage Center Command	Loss of	Failed electronics as-sociated with wheels engage center command	None, if wheels not disengaged. If center wheels are disengaged it will not be possible to reengage them	None	Vehicle mobility	3	5	
	Continuously on	Failed electronics as-sociated with wheels engage center command	Disengaged center wheels become re-engaged	None	Vehicle mobility	3	5	

TABLE IV.3-2 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMAND AND CONTROL SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Locomotion Continuous Select	Loss of	Failure of locomotion continuous select electronics	No variability in locomotion	Preset locomotion steps	Locomotion variability	3	5	
	Continuously on	Failure of locomotion continuous select electronics	Vehicle locomotes until batteries discharge	None		1	5	
Locomotion Stop Select Right Command	Loss of	Failed locomotion stop select right command electronics	No vehicle stop after continuous locomotion start	Locomotion stop select left capability	Vehicle mobility and navigation	2	5	
	Continuously on	Failed locomotion stop select right command electronics	Cannot stop vehicle after continuous locomotion has commenced	None	Vehicle useful life	1	5	
Locomotion Stop Select Left Command	Loss of Continuously on	BASICALLY, THE SAME AS LOCOMOTION STOP SELECT RIGHT COMMAND						

TABLE IV.3-3

FAILURE MODE AND EFFECTS ANALYSIS - TELEVISION SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: MISSION	Failure Class	Failure Probability	Remarks
Camera Clock and Sequencer	No Seq. and Clock Output	a) Faulty electronics b) Faulty connections c) loss of command d) loss of power	a) no vidicon filament voltage b) no TV Power Supply output c) no blanking pulses d) no vidicon prepare gate e) no horizontal sweep control f) no vertical sweep control	None None None None None None	Loss of TV video	1	3	Provide redundant clock and sequencing circuits
	Shorted gate output to Reg. P.S.	a) faulty electronics b) faulty connections	Continuous drain on main battery	None	Battery energy would be continuously drained, which could reduce mission time drastically	2	4	
	Shorted gate output to vidicon filament supply	a) faulty electronics b) faulty connections	Continuous drain on main battery	None	Battery energy would be continuously drained, which could reduce mission time drastically			
Regulated Power Supply	No output	a) faulty electronics b) faulty connections c) loss of power	No power to: a) sweep circuits b) H.V. circuits c) Video amp circuits	None None None	Loss of TV video	1	4	
	Shorted power gate	a) faulty electronics b) faulty connections	Continuous drain on main battery	None	Battery energy would be continuously drained, which could drastically reduce mission time	2	5	
Vidicon Filament Supply	Shorted Power gate	a) faulty electronics b) faulty connections	Continuous drain on main battery	None	Battery energy would be continuously drained, which could drastically reduce mission time	2	5	
Vidicon Filament Supply	No output	a) faulty electronics b) faulty connections c) loss of power	No filament power	None	Loss of TV video	1	5	Redundancy should be provided wherever weight and space permit.
Preamp	No output	a) faulty electronics b) faulty connections c) loss of power	No video	None	Loss of TV video	1	5	Redundancy should be provided wherever weight and space permit.
Video Amp	No output	a) faulty electronics b) faulty connections c) loss of power	No video	None	Loss of TV video	1	5	Redundancy should be provided wherever weight and space permit.
Aperture Connection	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of video scan compensation	None	Degradation of TV resolution	3-4	5	

TABLE IV.3-3 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - TELEVISION SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: MISSION	Failure Class	Failure Probability	Remarks
Video clamp	No output	a) faulty electronics b) faulty connections c) loss of power	DC shift in Video level	None	Degradation of TV contrast	3-4	5	Design so that loss of video clamp does not cause catastrophic video loss.
Video processor	No output	a) faulty electronics b) faulty connections c) loss of power	No output video	None	Loss of TV video	1	4	
Vidicon Face Plate Heater	Open Heater	a) faulty heating element b) faulty cable or connections		None		4	5	May not be required.
Calibrated Telemetry Drivers	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of T/M data points.	None	None	4-5	5	Approximately 10 TV T/M data points.
Prepare Read Gate	No output	a) faulty electronics b) faulty connections c) loss of power	a) loss of vertical sweep amplitude control b) loss of horizontal sweep amplitude control c) loss of horizontal blanking sync d) loss of vertical blanking sync e) loss of vidicon prepare read gate signal	None	Loss of TV video	1	3	
Vertical Sweep Amplitude Control	No output	a) faulty electronics b) faulty connections c) loss of power	No control on vertical picture size	None	Enlarged or shrunk TV picture	3-4	5	
Horizontal Sweep Amplitude Control	No output	a) faulty electronics b) faulty connections c) loss of power	No control on Horizontal picture size	None	Enlarged or shrunk TV picture	3-4	5	
Horizontal Blanking Generator	No output	a) faulty electronics b) faulty connections c) loss of power	a) loss of Horizontal blanking in TV picture b) loss of Horizontal sync	None	a) Horizontal retrace lines in TV picture b) Possible loss of Horizontal sync	3	5	Assumes free running horizontal sweep generator in the event of horizontal blanking generator loss.
Vertical Blanking Generator	No output	a) faulty electronics b) faulty connections c) loss of power	a) loss of vertical blanking in TV picture b) loss of vertical sync	None	a) Vertical retrace lines in TV picture b) Possible loss of vertical sync	3	5	Assumes free running vertical sweep generator in the event of vertical blanking generator loss

TABLE IV. 3-3 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - TELEVISION SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: MISSION	Failure Class	Failure Probability	Remarks
Horizontal Sync and Sweep Generator	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Horizontal Sweep	None	Loss of TV video	1	4	
Vertical Sync and Sweep Generator	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Vertical Sweep	None	Loss of TV video	1	4	
Horizontal Deflection Amplifier	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Horizontal Sweep	None	Loss of TV video	1	4	
Vertical Deflection Amplifier	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Vertical Sweep	None	Loss of TV video	1	4	
Blanking Mixer	No output	a) faulty electronics b) faulty connections c) loss of power	a) loss of vertical retrace blanking b) loss of horizontal retrace blanking	None	a) loss of blanking during retrace b) Possible effect on contrast	3	5	
Vidicon Prepare Read Gate	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Beam Current Control	None	Severe degradation of TV picture	2-3	5	
Read Sync Oscillator	No output	a) faulty electronics b) faulty connections c) loss of power	Loss of Read Sync Burst Signal	Picture may be restored at DSIF	Loss of sync at DSIF	3-4	5	
High Voltage Converter	a) loss of +500V and/or b) loss of -120V	a) faulty electronics b) faulty connections c) loss of power	Loss of TV Raster	None	Loss of TV	1	2	Redundant high voltage converters in an either-or configuration are recommended.
÷2HV Sync	Loss of output	a) faulty electronics b) faulty connections c) loss of power	Retrace lines in video	None	Interference in TV picture	4	5	
Align Current Regulator	Loss of output	a) faulty electronics b) faulty connections c) loss of power	Defocused Picture	None	Loss of TV Resolution	3-4	5	
Align Coil	Open or shorted		Defocused Picture	None	Loss of TV Resolution	3-4	5	
Deflection Yoke	Open or shorted		Severe Degradation of Deflection	None	Loss of TV Resolution	3-4	5	
Lens		a) Physical Misalignment b) moon dust	a) loss of light input b) defocused picture	None	a) loss of TV picture b) poor TV resolution	2	5	

TABLE IV.3-3 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - TELEVISION SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: MISSION	Failure Class	Failure Probability	Remarks
Light Sensor Array and Light Summer	Loss of output	a) faulty connections b) faulty electronics c) loss of power	Too much incident light causes a washed-out picture. Too little incident light causes a very weak picture.	None	Severely affected video picture depending on moon conditions	2	5	
Light Filter Control	Loss of output	a) faulty connections b) faulty electronics c) loss of power	Too much incident light causes a washed-out picture. Too little incident light causes a very weak picture.	None	Severely affected video picture depending on moon conditions	2	3-4	
Light Filter Drive	Loss of output	a) faulty connections b) faulty electronics c) loss of power	Too much incident light causes a washed-out picture. Too little incident light causes a very weak picture.	None	Severely affected video picture depending on moon conditions	2	2-3	

TABLE IV.3-4

FAILURE MODE AND EFFECTS ANALYSIS - COMMUNICATIONS SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: Mission	Failure Class	Failure Probability	Remarks
Antenna & Diplexer	No RF in to receiver and none transmitted	Mechanical failure in antenna structure	High VSWR looking into antenna from diplexer	None	Mission abort	1	5	These elements are critical in their influence upon the system as all communications, received and transmitted, must pass through them. It is imperative that maximum use of parts and materials be used that are capable of withstanding the lunar environment with minimum degradation or change of parameters.
		Dielectric failure or loss of dielectric support and integrity	High VSWR looking into antenna from diplexer	None	Mission abort	1	5	
		Diplexer failure	High VSWR between antenna and diplexer	None	Mission abort	1	5	
			High VSWR between diplexer and receiver or diplexer or P.A. or both	None	Mission abort	1	5	
VHF Transmitter	No output	Failed final power amplifier	Low power RF output but no high power	None	TV video lost if Surveyor is in null with respect to SLRV	3	4	This failure will not inhibit completion of the mission. Steering the vehicle out of this null should make continued operation possible.
		Failed low power amplifier	No RF output, low or high	None	Mission abort	1	4	
		Failed exciter	No RF output, low or high	None	Mission abort	1	5	
	No video output	Failed modulator	No video but center frequency RF only	None	Mission accomplishment, loss of TV & TM	1	5	
Input Selector	No output	Fails open or develops high impedance source referred to modulator	No video but center frequency RF only	None	Mission failure, loss of TV & TM	1	5	If TV or DIBSI is locked out the failure is catastrophic, if ranging is lock out it is critical and if TM is locked out, it is major.
	Fixed output	Input selector fails in one of four positions	No output change as commanded	None	Data received	1-3	5	
DIBSI Data Processor	Multiple outputs	Selector develops high level of crosstalk	Signals intermixed	None	TM and TV signal interference	2	5	
DIBSI Data Processor	No DIBSI output	Summer open failure	No DIBSI data or DIBSI calibrate	None	Loss of all DIBSI data	2	5	
	DIBSI TM data only	Summer failure SCO 1 failure	No DIBSI calibrate, force or acceleration data	None	Loss of soil measurement	2	5	

TABLE IV.3-4 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMUNICATIONS SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: Mission	Failure Class	Failure Probability	Remarks
DIBSI Data Processor (Continued)	DIBSI TM data only (continued)	SW1 and SW2 failed open	No DIBSI data or DIBSI calibrate	None	Loss of soil measurement data	2	5	
	DIBSI status data	SCO #2 failure or SCO #2 input end of summer	No DIBSI status data via TM	None	Loss of status information	3-4	5	
	Loss of DIBSI calibration	Calibrate source failure	No output	None	No DIBSI data scale factor	2-3	5	
Command Receiver	No output	Loss of any stage or local oscillator or demodulator	Vehicle status remains unchanged as a result of no commands	None	Mission abort	1	5	Redundant command receivers should be considered since this is a critical item that must operate for mission success.
	Loss of command signal output	Failure of command signal network	Vehicle status remains unchanged as a result of no commands	None	Mission abort	1	5	
	Loss of AGC	Failure in AGC network	No receiver AGC	None	Indeterminate	4	5	
Input Switching Unit #1 (Surveyor Based)	No output	Failure in switches or controls making outputs appear as open	No SLRV TV video, DIBSI, or TM transmitted out of Surveyor	None	Mission abort	1	5	
	Fixed output	Switching units stay in one position	No output change as commanded	None	Some information loss	1-3	5	The information loss is a function of the failed switch position. With a failure excluding SLRV TV the class is catastrophic, with DIBSI and range and bearing excluded it is critical, and with SLRV TM excluded it is major.
Input Switching Unit #2 Surveyor Based	No output	Failure in switches or controls making outputs appear as open	No range and bearing data transmission	None	No range and bearing data	2	5	
	Fixed output	Switch fails in locked position	Data from range or bearing only, but not both	None	Mission contour mapping	4	5	

TABLE IV. 3-5

FAILURE MODE AND EFFECTS ANALYSIS - TELEMETRY SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: Telemetry	Failure Class	Failure Probability	Remarks
Axle 1 — Data Processor	Transfer register	1) faulty electronics 2) loss of timing 3) faulty connections 4) loss of power	loss of digital data from Axle 1	None	Loss of digital T/M inputs from Axle 1	4	5	
	Analog commutator	1) faulty electronics 2) loss of timing 3) faulty connections	Loss of analog data from Axle 1	None	Loss of analog T/M inputs from Axle 1	4	4	
	Timing and program	1) faulty electronics 2) loss of timing 3) faulty connections	Loss of both analog and digital data from Axle 1	None	Loss of both digital T/M inputs and analog T/M inputs	3	5	Timing and program should be made as redundant as possible within the range of allowable weight and space.
	Multiplexer	1) faulty electronics 2) loss of timing 3) faulty connections	Loss of both analog and digital data from Axle 1	None	Loss of both digital T/M inputs and analog T/M inputs	3	5	
Axle 2 — Data Processor	Transfer register	1) faulty electronics 2) loss of timing 3) faulty connections 4) loss of power	Loss of digital outputs from Axle 2	None	Loss of digital T/M inputs from Axle 2	3	4	
	Analog commutator	1) faulty electronics 2) loss of timing 3) faulty connections 4) loss of power	Loss of analog outputs from Axle 2	None	Loss of analog T/M inputs from Axle 2	3	4	
	Timing and programming	1) faulty electronics 2) loss of timing 3) faulty connections 4) loss of power	Loss of both analog and digital data from Axle	None	Loss of both digital T/M inputs and analog T/M inputs	2	5	
	Multiplexer	1) faulty electronics 2) loss of timing 3) faulty connections 4) loss of power	Loss of both analog and digital data from Axle 3	None	Loss of both digital T/M inputs and analog T/M inputs	2	5	
Axle 3	Scientific experiment	1) faulty electronics 2) faulty connections 3) loss of power	Loss of scientific experiment data	None	DIBSI experiment (force and acceleration)			

TABLE IV.3-4 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - COMMUNICATIONS SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: Mission	Failure Class	Failure Probability	Remarks
Input Pre-selector	No output	Opens in preselector	No range & bearing or DIBSI baseband	None	Complete mission fulfillment	2	5	
VHF Xmtr	No output	Failed exciter, PA or other portion of Xmtr	No SLRV command capability	None	Mission abort	1	5	Loss of communication to SLRV from Surveyor and/or group station.
Antenna and Diplexer	No RF transmitted or received	Failure in mechanical structure, dielectric failures, diplexer failures	High VSWR in system	None	Mission abort	1	5	
VHF Re-ceiver — for Video, TM, & DIBSI	No output	Loss of any stage, de-modulator or local oscillator	No data return	None	Mission abort	1	5	For all but range and bearing measurements the range and bearing receiver should be redundant to this receiver to insure video, TM, and DIBSI return.
VHF Re-ceiver — for Range & Bearing, in Conjunc-tion with VHF Rcvr above	No output	Loss of any stage, de-modulator or local oscillator	Loss of range & bearing measurement capability	None	Mapping capability lost	2	5	
Range & Bearing Circuits	Loss of measurement capability	Circuit failures	No return when measurement is processed	None	Mapping capability lost	2	4	
	Erroneous or ambiguous data	Parametric changes	Inconsistent data	None	Mapping capability lost	2	4	

TABLE IV.3-5 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - TELEMETRY SUBSYSTEM

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: Telemetry	Failure Class	Failure Probability	Remarks
Axle 3 (Continued)	Vehicle control	1) faulty electro-mechanical devices	Continuous vehicle control activation	None		2	5	Deactivating vehicle by placing in Pwr., charge may alleviate problem. If not, vehicle performance will be seriously compromised.
			No vehicle control activation	None		2	5	
Central Data Processor	Main commutator	1) faulty electronics 2) loss of timing 3) faulty connection 4) loss of power	Loss of digital and analog data from Axles 1	None	Loss of all T/M except DIBSI experiment	2	5	Redundancy here is preferred over even the individual axle data processors in that all TM data funnels through this data processor.
	Crystal oscillator	1) faulty electronics 2) faulty connection	Loss of digital and analog data from Axles 1	None	Loss of all T/M except DIBSI experiment	2	5	
	Master timing and program	1) faulty electronics 2) faulty connection 3) loss of timing 4) loss of power	Loss of digital and analog data from Axles 1	None	Loss of all T/M except DIBSI experiment	2	5	
	Output logic	1) faulty electronics 2) faulty connection 3) loss of timing 4) loss of power	Loss of digital and analog data from Axles 1	None	Loss of all T/M except DIBSI experiment	2	5	
	Frame sync generator	1) faulty electronics 2) faulty connection 3) loss of timing 4) loss of power	Loss of Frame sync signal	Retrieval of data at ground station with difficulty	Loss of Frame Reference	3-4	5	
	Parity generator	1) faulty electronics 2) loss of power	Loss of parity bit faulty of parity bit	None	Loss of parity check	4	5	
	Sub carrier OSC (output logic)	1) faulty electronics 2) loss of power	Loss of all T/M data except DIBSI experiment	None	Loss of all T/M data except DIBSI experiment	2	5	
	Sub carrier OSC DIBSI experiment A	1) faulty electronics 2) loss of power	Loss of DIBSI experiment A data	None	Loss of DIBSI experiment "A" data	3	5	
	DIBSI experiment B	1) faulty electronics 2) loss of power	Loss of DIBSI experiment B data	None	Loss of DIBSI experiment "B" data.	3	5	

TABLE IV. 3-6

FAILURE MODE AND EFFECTS ANALYSIS - DIBSI SUBSYSTEM

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
DIBSI Tube	Loss of Force Generator	1) Motor failure 2) Gear Train Failure 3) Binding hammer or lead screw 4) Loss of hermetic seal, leading to 1), 2), 3). 5) Faulty cabling	No DIBSI tube displacement.	Dual DIBSI configuration is essentially redundant	Loss of scaling factor	4	3	Design so that a) both instruments are completely independent. b) motor & gear train can function in low pressure environment for limited time. c) detect loss of pressure prior to failure.
	Reduced Force Generator Energy	1) Rubbing hammer 2) Broken negator spring	Reduced hammer force, lower force transducer measurements.	Perform additional hammer strokes per measurement.	Lengthen measurement time	5	5	Design so that breakage of one or more negator springs does not bind hammer.
	Decreased Cycling Rate	1) Rubbing hammer 2) Reduced motor torque 3) Reduced gear train and screw efficiency 4) Loss of hermetic seal, leading to 2) and 3)	Increase hammer lift time.	None	Lengthen measurement time	5	4	Design so that a) motor & gear train can function in low pressure environment for limited time. b) detect loss of pressure prior to failure.
	Loss of Force Transducer Data	1) Transducer failure 2) Faulty cabling	No force data received	None	Reduction in quality of measurement, giving reduced accuracy of scaling factor.	5	5	
	Loss of Acceleration Transducer		No acceleration data received					
	Loss of Temperature Transducer		No Pad Temperature Data received	Temperature data from other pad has some value.				
	Binding Tube in Deployment Guides	1) Soil in deployment guides	Cannot be deployed	Hammer several strokes to attempt to loosen	Loss of scaling factor	4	?	
			Cannot be Retracted	Hammer several strokes to attempt to loosen	Mission abort if DIBSI cannot be dragged by vehicle.	1 - 3	?	Design so that single DIBSI may be released from vehicle.
	DIBSI Tube wedged in soil	Geometry of rocks around pad.	Cannot retract	Rock vehicle to loosen tube	Mission Abort	1	?	Design so that a) single DIBSI may be released from vehicle or b) pad may be released from tube.

TABLE IV. 3-6 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - DIBSI SUBSYSTEM

ITEM AND TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS AND LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Deployment Assembly	Loss of Deployment & Retraction Force	1) Motor failure 2) Gear train failure 3) Loss of hermetic seal, leading to 1) or 2). 4) Broken or Binding Tape	Cannot retract deployed DIBSI	None	Mission abort, if DIBSI cannot be dragged by vehicle.	1 - 3	4	Design so that, a) single DIBSI may be released from vehicle. b) Detect loss of pressure prior to failure.
			Cannot deploy retracted DIBSI	None	Loss of scaling factor	3	5	Detect loss of pressure prior to failure
	Reduction in Retraction Force	1) Reduced Motor Torque 2) Reduced gear train efficiency 3) Loss of hermetic seal, leading to 1) or 2)	May not be able to retract DIBSI, or increased retraction time.	Rock vehicle to reduce retraction force.	Mission abort if DIBSI cannot be dragged by vehicle.	1 - 3	4	Design so that, a) single DIBSI may be released from vehicle. b) detect loss of pressure prior to failure.
	Failure to stop deployment or retraction	1) Failure of limit switch 2) Faulty cable.	Deployment motor continues to draw current.	None	Discharge Battery	2	5	Design so that deployment actuation signals are limited in duration, and will cut off motor power if limit switch does not.
	Loss of Penetration Measurement	1) Failure of potentiometer 2) Broken or binding negator spring. 3) Faulty cable.	No penetration data.	Limit number of DIBSI strokes to avoid breaking tape. Integrate force acceleration data.	Possibly reduce quality of data.	4	5	Experiment can be performed without penetration data, at increased risk of failure of DIBSI deployment mechanism.

TABLE IV. 3-7

FAILURE MODE AND EFFECTS ANALYSIS - BASIC VEHICLE

FAILURE EFFECTS ANALYSIS - BASIC VEHICLE

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Wheel Drive Assembly	No Driving Torque	1) Failure of Motor	Change in normal motor current. Reduction of mobility.	Free Wheeling Clutch	Reduced mobility in rough terrain. Very little effect on relatively smooth terrain.	2 - 4	3	Design so that a) motor & gear train can function in low pressure environment for limited time. b) Detect loss of pressure prior to failure.
		2) Failure of Gear Train					4	
		3) Failure of Brake					5	Predominate brake failure mode is loss of braking action and inability to transmit torque.
		4) Clutch not engaged (selective clutch)		None			5	
		5) Loss of hermetic seal, leading to 1), 2), 3), 4).		Free Wheeling Clutch (except 4)			3	Design so that a) enclosed mechanisms can function in low pressure environment for limited time. b) Detect loss of pressure prior to failure.
		6) Binding of external bearings		None		1 - 3	?	Current design has bearings shielded from soil. Reaction torque from 9 inch radius wheel plus driving torque of wheel drive assembly will be able to overcome considerable bearing torque.
		7) Faulty Cabling		Free Wheeling Clutch		2 - 4	5	

TABLE IV.3-7 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - BASIC VEHICLE

FAILURE EFFECTS ANALYSIS - BASIC VEHICLE - (continued)

Table 7

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSE	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Wheel Drive Assembly	Reduced Driving Torque	1) Reduced Motor Torque	Change in normal motor current. Reduction of mobility.	None	May reduce mobility in rough terrain. No effect on relatively smooth terrain	2 - 4	4	This mode of failure may be difficult to detect. Design so that a) motor & gear train can function for limited time in low pressure environment. b) detect loss of pressure prior to failure.
		2) Reduced Gear Train Efficiency					3	
		3) Loss of hermetic seal, leading to 1), 2).					3	
		4) High friction in External Bearings.					?	This mode of failure may be difficult to detect. Current design has bearings shielded from soil.
	Cannot clutch for Free Wheeling	Non Selective - 1) Pyrotechics failure 2) Faulty Cabling	Cannot Free Wheel	None	Same as no driving torque failure.	2 - 3	5	This failure mode is of interest only when a prior wheel drive failure has occurred.
		Selective - 1) Solenoid Failure 2) Mechanism Binding 3) Faulty Cabling			For prior wheel drive failure: same as no driving torque.	2 - 3	5	Same as Above.
					For Odometer purposes: reduction of Odometer accuracy.	5	5	Failure mode of little interest when clutching is not for purpose of negating prior wheel failure.
	Cannot Re-engage Clutch for driving (selective)	1) Solenoid Failure 2) Mechanism Binding 3) Faulty Cabling	Cannot derive driving torque from wheel. Reduction of mobility.	None	Same as no driving torque failure.	2 - 4	5	
	Loss of Wheel Brake	1) Failure of brake mechanism.	Probably not detectable on singular occurrence.	None	May limit grade holding capability.	5	5	Current design has loss of braking ability only as major failure mode. More than one wheel brake assembly will have to fail before grade holding or coasting will be materially affected.
	Loss of Odometer	1) Failure of magnetor switch. 2) Faulty Cabling	No Odometer signal	Odometers on two wheels providing full redundancy.	On singular failure basis, no effect. If both fail, mapping accuracy reduced and vehicle control more difficult	5	5	Current design has odometers on two wheels, giving full redundancy. Command & Control could be able to use inputs from both Odometers for stopping locomotion after one step.

TABLE IV. 3-7 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - BASIC VEHICLE

FAILURE EFFECTS ANALYSIS - BASIC VEHICLE (continued)

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Steering Assembly	No steering response	1) Motor Failure 2) Gear Train Failure 3) Loss of pressurization leading to 1), 2)	Partial loss of maneuverability, no change in position indication	Two axle steering technique gives some maneuvering capability with one axle inoperable.	Seriousness is function of steering position at failure. In all cases refuction in maneuverability.	1 - 3	4	Design so that assembly has self-centering capability, if drive train fails.
		4) Limit switch failure	Continuing power drain. Also, same as above.		Seriously limits mobility if failure in extreme position. Discharge battery.		5	Same as above. Also limit time of power on signal from command and control
		5) Faulty Cable	Same as 1), 2), 3) above.		Same as 1), 2), 3) above		5	Same as 1), 2), 3) above.
	Reduced Steering Torque	1) Reduced Motor Torque 2) Reduced Gear Train and Bearing Efficiency. 3) Loss of pressurization leading to 1), 2).	Cannot achieve desired axle position in rough terrain.	Move vehicle to position where required steering torque is reduced.	Same loss in maneuverability.	3	4	Design so that a) motor & gear trains can operate in low pressure environment for limited time. b) detect pressure loss prior to failure.
	Loss of Position Indicator	1) Switch failure 2) Faulty Cable	No position indication from one axle.	Use indication from other axle.	May increase vehicle control problems.	5	5	Loss of position indication may also affect axle synchronization & axle limit stops. (see no steering response, above)
TV Azimuth Head	Loss of Rotation	Similar to Steering Assembly	TV Azimuth does not vary.	Step front axle for limited coverage. Vary vehicle attitude for full azimuth coverage.	Effect on mission is function of position at failure. In all positions mission time greatly increased.	2 - 3	4	Most desireable position at failure is straight ahead.
TV Height Elevation Assembly	No height change.	Similar to Steering Assembly	No stereo effect in TV pictures.	Achieve necessary stereo by mono-pictures from adjacent stations.	Loss of direct stereo. Increase survey time to perform adjacent station stereo.	3	4	
Thermal Control	Compartment overheated. (high sun angle)	1) Thermal Switch stuck in non-conducting position 2) Radiator broken or obscured.	Telemetry indications or equipment malfunctions.	Reduce duty cycle of high dissipation equipments in area.	Reduce allowable operating time, or assume increased failure risk	3 - 4	5	Design so that conduction paths of high dissipation equipments are split between two or more switches.
		3) Heating pellet in internal dissipation position.				5	5	The few additional watts from the heating pellet should not seriously limit duty cycle.

TABLE IV. 3-7 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS - BASIC VEHICLE

FAILURE EFFECTS ANALYSIS - BASIC VEHICLE (continued)

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Thermal Control	Compartment Under Temperature. (Night or very low sun angle)	1.) Thermal switch stuck in conducting position	Telemetry indications or equipment malfunctions.	None	Various	1 - 4	5	This failure mode of significance primarily during lunar night. Any such failure on compartment 2 will damage battery. Investigate which switch position is more desireable failure mode.
		2) Heating pellet in external dissipation position.						Same as above.
		3) Failed heating pellet.					–	Inherent reliability of device very high.
Interconnect	Open conductor	1) Fatigue 2) Rock damage 3) Failed connection		None	Various	1 - 5	3	Parallel critical signals. Thermal interface at compartments anticipated to be major failure area.
	Shorted conductor	1) Rock damage 2) Failed connection					5	Thermal interface at compartments anticipated to be major failure area.
Clinometer	No output on one axis	1) Faulty sensor 2) Failed electronics 3) Faulty Cabling	No telemetered Data.	Use TV pictures as partial substitute.	Degraded survey accuracy	4	5	Design so that both axis are completely independent functionally.
	Reduction of accuracy	1) Faulty sensor 2) Faulty electronics	Difficult to detect minor reductions. May do rough cross check with vehicle tilt switches	Use TV pictures as partial substitute	Some degradation of survey accuracy.	4	5	

TABLE IV.3-8

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Power Subsystem	Loss of power	Battery failure	No high power available	None	No TV, DIBSI, or locomotion	1	3	Provide maximum battery capacity allowable, limit depth of discharge, and minimize cycles. Some telemetry possible with power derived directly from array.
		Array failure	No energy return to battery	Redundancy in array connection configuration	Mission life limited to battery capacity and energy stored therein at time of failure	1	5	
	Excessive power	Voltage limiter fails open	Battery subjected to overvoltage	None	Probable battery failure	1-2	5	The overvoltage can possibly be reduced by increasing operate time resulting in some loading effect. However, the power charge mode can not be entered since this places maximum overvoltage upon battery and some combination of excess bleeding. A charge must be accomplished without raising temperatures internally unduly.
	Loss of power	Voltage limiter fails short	Array power shunted through limiter	None	No power available to recharge battery	1	5	
	No Regulated +24 VDC	Series regulator fails open	No power available to electronics other than standby power	None	No TV, DIBSI, or TM available	1	4	Redundant series pass transistor recommended both for reliability and temperature considerations.
	Unregulated +24 VDC	Regulator fails short	Battery and solar bus applied to loads	Some internal regulation in individual loads may compensate for this loss	Operational sequence	2-3	4	If insufficient individual load regulation exists then operation must be tailored to best bus voltage.
	Converter Failure	Internal part failures	Loss of some standby voltages	None	Loss of TV video (no vidicon filament) and some TM	1	5	

TABLE IV.3-8 (Continued)

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Power Subsystem (Continued)	State of charge monitor failure	Fails to count forward or backward or counts erroneously	No TM data in data return or erroneous data	None	Mission life	2	4	The state of charge monitor is a necessary adjunct to mission success. If the battery state is unknown then its life expectancy can be significantly shortened by operating it without knowledge of output vs. input.
Television Subsystem	No TV video output	Camera clock and sequencer failures		None	Surveyor lunar roving vehicle navigation and mapping capability	1	1	
		Failure in internal power supply	No vidicon filament, or other supply voltages	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
		Failure in video pre-amp or amplifier	No video output to modulator	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
		Prepare - read gate failures	No video readout	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
		Video processor failure	No video output	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
		Sync generator failures	No horizontal sweep	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
		Deflection amplifier failures	No sweep	None	Surveyor lunar roving vehicle navigation and mapping capability	1		
	Degraded video	Failures in alignment coil, deflection yoke, or ÷ 2 HV sync	Defocusing, deflection degradation, or picture size	None	Degraded navigation and mapping capability	2-3	5	
		Light sensor and control, prepare - read gate or sweep amplitude controls	Contrast improper, tube surface degrades, picture size	None	Degraded navigation and mapping capability	2-3	5	

TABLE IV.3-8 (Continued)

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Command and Control Subsystem	Loss of one or more action (locomotion and steer) commands	Failure in locomotion and steer command electronics	Vehicle mobility and operational flexibility	None	Longer time required to survey site	3	4	
	Change modes	Modal command failure and individual commands associated with the particular state	Depends upon mode in originally and the mode desired to be in	Individual sub-subsystem command	Mission abort	1	4	If the electronic system stays locked in any single state the mission is substantially aborted. Any failure to change state will result in immediate loss of desired functioning, such as, if locked in charge mode no TV or DIBSI is possible or will cause loss of desired functioning as soon as batteries are depleted.
	Loss of individual command capability	Failure in end of particular command chain	Loss of some particular command function	None	Minor effect to mission abort	1-5	3	The command channels of critical importance, such as those required to take TV. Pictures, DIBSI, and charge mode should incorporate redundant capability associated with getting the command through.
Communications Subsystem	No signals to command and control	Failures in command receiver, antenna or diplexer	SLRV remains in last state prior to failure	None	Mission abort occurs	1	5	
	No video, DIBSI, or TM	Transmitter failure	No ground station response to commands	None	Mission abort occurs	1	4	
		Receiver and processing failures aboard Surveyor	No ground station response to commands	None	Mission abort occurs	1	5	
	No DIBSI data	DIBSI data processor failure	No DIBSI data input to transmitter	None	Loss of DIBSI information	2	5	
	No range and bearing data	Failure of range and bearing circuits aboard surveyor	No response to range and bearing command	None	Loss of one major mapping parameter	2	5	
Telemetry Subsystem	Loss of housekeeping data	Failure of associated sensors, conditioners, etc.	Loss of inputs to SCO's	None		2-4	5	

TABLE IV.3-8 (Continued)

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

Item and Title	Assumed Failure	Possible Causes	Symptoms and Local Effects	Compensating Provisions	Effect On: SLRV Mission	Failure Class	Failure Probability	Remarks
Telemetry Subsystem (Continued)	Loss of power subsystem data	Failure of associated sensors, conditioners, etc.	Loss of inputs to SCO's	None	Mission abort may occur if power profile is not known and it can not be synthesized	2	5	
	Complete TM loss for either one or both axies	Failure of commutators, timing, SCO's or multiplexing	No input to transmitter	None	Mission abort near	2	3	

TABLE IV. 3-8 (Continued)

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
DIBSI	Loss of data from one tube	1) Loss of Force Generator 2) Faulty Cabling	No data returned.	Dual DIBSI Configuration is essentially redundant.	Loss of soil mechanics scaling factor	4	3	Design so that a) both instruments are completely independent.
	Cannot deploy and/or detract DIBSI	1) Failed deployment mechanism. 2) Binding tube in deployment guides. 3) Tube wedged in soil.	Cannot deploy and/or detract tube.	Rock vehicle to reduce retraction force.	Mission abort if DIBSI cannot be retracted or dragged by vehicle. Loss of single tube data if vehicle cannot be deployed	1 - 4	? - 4	Design so that either tube can be jettisoned.
Basic Vehicle	Loss of wheel driving torque Reduction in wheel driving torque.	1) Failure in drive train 2) Faulty Cabling	Change in normal motor current. Reduction of mobility.	Free Wheeling Clutch	Reduced mobility in rough terrain. Very little effect on relatively smooth terrain.	2 - 4	3	Probability of failure of more than one wheel negligible.
				None		1 - 3	?	Current design has bearing shielded from soil. Reaction torque from 9 inch radius wheel plus driving torque of wheel drive assembly will be able to overcome considerable bearing torque.
	No Steering Response (single axle)	1) Failure in drive train 2) Faulty Cabling	Steering position indicator shows no response to steering commands.	Remaining axle control gives some maneuvering ability.	Seriousness is a function of axle position at failure and of surface roughness. In all cases there is some loss of maneuverability.	1 - 3	4	Design so that assembly has self-centering capability if drive train fails.
	Loss of TV Variable Azimuth	1) Failure in drive train 2) Faulty Cabling	TV azimuth does not very.	Step front axle for limited coverage. Vary vehicle attitude for full azimuth coverage.	Effect on mission is function of position at failure. In all cases, mission time increased.	2 - 3	4	Most desireable position at failure is straight ahead.
	Loss of TV elevation capability	1) Failure in drive train 2) Faulty Cabling	No Stereo effect in TV pictures	Achieve necessary data by mono-pictures from adjacent stations	Loss of stereo. Extend mission time	3	4	
	Over temperature in electronics compartment (high sun angle)	Thermal switch stuck in non-conducting position.	Telemetry indications or equipment malfunctions.	Reduce duty cycle of equipment	Reduce system duty cycle or assume increased failure risk.	3 - 5	5	Design so that conduction paths of high dissipation equipments are shared between two or more thermal switches.

IV 3-34

TABLE IV. 3-8 (Continued)

SUMMARY - MAJOR FAILURE MODES AND EFFECTS ANALYSIS FOR THE SLRV

B.B.

ITEM and TITLE	ASSUMED FAILURE	POSSIBLE CAUSES	SYMPTOMS and LOCAL EFFECTS	COMPENSATING PROVISIONS	EFFECT ON MISSION	FAILURE CLASS	FAILURE PROBABILITY	REMARKS
Basic Vehicle	Under temperature in electronics compartments. (night or low sun angle)	Thermal switch stuck in conducting position.	Telemetry Indications	None	Various	1 - 4	5	This failure mode of significance primarily during lunar night. Compartment 2 in battery area highest risk area.
	Faulty Cabling	1) Fatigue 2) Rock damage 3) Failed connection	Various	None	Various	1 - 5	3	Paralleling of critical signals may be feasible.
Surveyor Basic Bus (excluding SLRV unique equipment)	Loss of data transmission capability	Various	No response from vehicle, and/or Surveyor	None	Mission Abort	1	1	
	Limited Duty Cycle	1) Power limitations 2) Thermal limitation		Reduce SLRV duty cycle	Extend Mission Time	3	?	

APPENDIX IV

RELIABILITY GOALS

A necessary part of the functional specifications generated in Phase I is a description of the desired reliability performance. Of the three major phases of the SLRV total mission, the flight and landing phase and the deployment phase offer considerably less reliability challenge than the lunar-survey phase. From the studies accomplished to date, one can conclude that there are two primary areas of interest during the lunar-survey phase which should be reflected in any reliability considerations. These are, first, to accomplish the mission in one lunar day or less with the maximum probability of success, and second, to design a high probability of lunar-night survivability into the system should conditions dictate a survey mission of longer than 10 Earth-days.

To assure recognition of these two areas, GMDRL has chosen to describe the SLRV total mission-reliability goals in terms of two missions, one of 10 Earth-days, and one of 28 Earth-days lunar duration. The 28 Earth-day mission is identical to the 10 Earth-day mission except that it requires surviving one lunar night.

The SLRV System Reliability goals for contractor-supplied equipment for a 10 Earth-day lunar survey mission is .8, and for a 28 Earth-day lunar survey mission is .7. Table IV. 4-1 lists the allocations for each of the mission phases for both mission durations.

Table IV. 4-1

SLRV RELIABILITY GOALS CONTRACTOR-SUPPLIED EQUIPMENT

	Flight and Landing	Deployment	Lunar Survey	Total
10 E-Day Mission	.98	.97	.84	.80
28 E-Day Mission	.98	.97	.74	.70

The flight and landing goals are based primarily on engineering judgment and are believed attainable under current system concepts. The lunar-survey goals are similar to the predicted reliabilities discussed in Appendix II - Reliability Prediction.

The lunar-survey phase goals of .84 and .74 have been allocated to the subsystems as shown in Table IV. 4-2. The decrease in reliability from the 10- to 28-day mission is the allocation for lunar-night survivability. The basis for the subsystem allocations is the reliability predictions performed to date, with minor changes.

At this point in the program it is not anticipated that the flight and landing goals and deployment goals will be allocated to the SLRV subsystems. One exception may be in the case of that equipment which is "one-shot" in nature and associated with the deployment phase, such as the deployment mechanism and any erectable mechanisms.

Table IV. 4-2

SLRV SUBSYSTEM RELIABILITY ALLOCATION

	10 E Day	28 E Day
Power and Control		
Communications	.997	.996
Command & Control	.958	.955
Power	.988	.978
Basic Vehicle		
Wheels & Drive	.965	.936
Steering	.998	.988
Thermal	.997	.985
Interconnect & Structures	.988	.956
Instrumentation		
TV	.983	.973
DIBSI	.989	.969
Telemetry	.975	.973
Clinometer	.998	.997
Surveyor		
SLRV Equipment	.993	.992
Total	.84	.74

Reliability goals for the contractor supplied OGE have been established to assist in preliminary systems design and maintainability activities. These goals are based entirely on engineering judgments of what would be both desirable and reasonable, without benefit of detailed equipment descriptions.

The goals are:

	10 E Day Mission	28 E Day Mission
No OGE failures which directly affect vehicle safety	.98	.97
Maximum of 3 hours unscheduled down time affecting mission accomplishment	.90	.88

APPENDIX V

COMPROMISED MISSION CAPABILITY

In Appendix III, Failure Mode and Effects Analysis, numerous failure modes were identified which did not result in mission abort. Many of these modes allow all or partial achievement of mission objectives, with reduced accuracy or increased mission time. The following paragraphs describe possible changes in the SLRV mission survey strategy to accommodate these failures and return the maximum amount of mission data.

1. Limited Basic Bus Operating Duty Cycle

   The mission survey would be performed in the normal manner with standby operation interspersed as necessary to allow Basic Bus recovery. Depending on the nature of the limitation, mission time may not be significantly increased, if the time can be profitably used for vehicle battery charge.

2. Loss of Vehicle High Power Transmit

   Case One: Vehicle Beyond the Range of Low Power Transmit With No Narrow Band TV Capability

   If the terrain is readily negotiable, the vehicle will be returned to the zone of low power coverage for a more detailed survey over the reduced survey area. The probability of successfully returning the vehicle becomes significantly smaller with conditions of rougher terrain.

   Case Two: Vehicle With Narrow Band TV Coverage

   The vehicle would be used to continue the normal-mode mission at a reduced operating rate.

Case Three: The Vehicle Within the Low Power Operating Range With No Narrow-Band Capability.

The vehicle would be used to conduct a detailed survey of the reduced area.

3. Loss of RF Range and/or Bearing

The mission would be performed similar to the normal mode mission with the following alterations: Emphasis would be given to TV location fixing, and landing points would be certified at somewhat smaller distances to partially allow for the reduced location accuracy.

4. Loss of Battery Charge Capability

The present design for the 100-lb. SLRV embodies a charge capacity to complete battery discharge of approximately 100 watt-hours. Depending upon the charge state at the time of failure, there would be from 50 - 100 watt-hours of energy remaining for the mission. The distance capability with this energy for the SLRV would be of the order of 500 - 1000 meters. The number is so small that a new partial mission definition is appropriate since this amount of work will not add depreciably to the site certification. The vehicle might go to the most effective vantage points within its capability for TV survey (perhaps DIBSI also) and continue in this way until system energy depletion.

5. Reduced Energy Storage Capability

If the storage capability is significantly decreased, the system life may be reduced. If 24-hour control capability is employed, performance is little affected. Should 12-hour control capability be employed, the operating energy of the system is reduced by the amount of the battery capacity loss per earth day. Mission plan would be unchanged.

6. Loss of All Telemetry Except DIBSI Sub-Carriers

   The survey would operate in the normal manner, with some loss of survey data, i.e., Clinometer and Odometer. Inability to monitor housekeeping functions would significantly increase vehicle failure probability. Vehicle system management would be based on ground models for items such as power and thermal.

7. Loss of All Video

   The vehicle would be operated blindly based on attitude data. The objective would be to gain slope data and soil strength measurements.

8. Degradation of TV

   Some of the effects on the mission to be expected from this would be a reduced day-time operating window, reduced vehicle operating speed, and an effectiveness loss in detecting and surveying landing points. Performance loss depends on the amount of loss of image quality and the type of image degradation, e.g., signal to noise reduction, sync difficulties, sweep distortions.

9. Loss of TV Elevation Drive

   Loss of stereo would increase real time decisions associated with steering, landing point search, and landing point certification. There is still a good chance of complete site certification using stereo generated from TV pictures taken from adjacent sites. If the elevation drive fails in the extended position, the heightened front compartment center of gravity could limit mobility in high terrain roughness.

10. Loss of TV Azimuth Stepping

    The least harmful position at failure is with the TV pointing in a generally forward or reverse direction. The azimuth can be varied through ± 30° by stepping the steering. A 360° survey would require repositioning the vehicle several times.

If the failure is in a side looking position, locomotion and search would be very difficult. In rough terrain such a failure could prevent achievement of most mission objectives.

11. Loss of One or Both Axis of Clinometer

The importance of this failure will depend somewhat upon the stability of the vehicle under TV elevation changes. It is expected that ground data processing can compensate in part for this failure mode. Mission strategy would be unchanged.

12. Loss of All DIBSI Data

The mission would continue in the normal mode with the exception that the only source of soil strength might be through TV observation. For example, if the DIBSI can be commanded, a fixed number of impact cycles might be performed and the penetration observed with TV before and after the tube was removed. Also vehicle sinkage would be observed and slip of the wheels measured by comparing odometer and stereo data.

13. Loss of One DIBSI Force Generator

The mission would proceed as before with the importance of the failure being dependent on the number of previous measurements and the test homogeniety. The major loss would be the pad scaling factor.

14. Loss of One Wheel Drive

This failure mode effects only the mobility of the vehicle. Depending on surface roughness, the seriousness ranges from critical to negligible. The necessity of going around what you no longer can go over would extend mission time. The survey strategy would probably remain unaffected.

15. Loss of One Steering Drive

This failure reduced vehicle maneuverability and on high roughness terrain could limit permissable areas of survey. No change in survey strategy is anticipated. Mission time would be extended.

16. Open Thermal Switch

The average system operating rate would be reduced but the mission strategy would be unchanged. The seriousness of the loss will depend on TV quality at high solar elevation.

APPENDIX VI
PREFERRED PARTS AND MATERIALS

A. INTRODUCTION

One of the tasks performed during the study program was a survey of available data and experience for the purpose of generating parts and materials lists applicable to the SLRV mission and environments. The lists generated contain the parts and materials from which the applicable SLRV parts and materials would be selected and the degree of space qualification where it exists.

The lists are not represented as being complete in either categories covered, or depth of coverage, but rather to indicate the areas in which a preferred parts and materials can be established based on existing data. In some areas, such as rotating devices and bearings in vacuum, the requirements of the SLRV are unique, so that additional testing must be performed prior establishment of preferred lists.

B. PARTS

The lists of preferred parts are given in Tables IV. 6-1 through IV. 6-13. These lists are only guides at present; however, where possible, the parts and materials listed will be used.

C. MATERIALS

The lists of preferred materials are given in Tables IV. 6-14 through IV. 6-17. These products have been used on successful space vehicles.

When the environmental extremes of the SLRV mission are more clearly defined, it may be necessary to use substitutes for some of the materials listed. When substitutions are made, these substitutes will be adequately tested and their capabilities demonstrated for qualification in the lunar environment.

TABLE IV.6-1
LIST OF PREFERRED PARTS, CAPACITORS

Dielectric Material	Description	Designation	Degree of Space Experience*	Anticipated Testing Requirements	Sources
Ceramic	Axial Lead General Purpose	MC81	NOTE 1	None	Hi-Q Div., Aerovox Co.
Ceramic	Radial Lead General Purpose	CK05, CK06	a	None	Hi-Q Div., Aerovox Co.
Mica	Dipped Mica	HRWDM10 HRWDM15 HRWDM19 HRWDM30	a	None	Electromotive Manufacturing Co.
Mica	Feed-Thru	CB75, CB76	a	None	Erie Technological Products
Mica	Stand-Off	CB85, CB86	a	None	Erie Technological Products
Mylar		CTM	a	None	General Electric Co.
Glass		CYFR 10 CYFR 15 CYFR 20	a	None	Corning Glass Works
Glass	Trimmer, Piston Type	PC	a	None	Corning Glass Works; Erie Resistor Corp.; JFD Corp.
Tantalum Oxide	Solid, Polarized	350D	a	None	Sprague Electric Co.

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-1 (Continued)
LIST OF PREFERRED PARTS, CAPACITORS

Dielectric Material	Description	Designation	Degree of Space Experience*	Anticipated Testing Requirements	Sources
Tantalum Oxide	Solid, Non-Polarized	151D	a	None	Sprague Electric Co.
Tantalum Oxide	Foil, Hermetically Sealed	15K, 16K	a	None	General Electric Co.

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TABLE IV.6-2
LIST OF PREFERRED PARTS, COILS, RF

Type	Inductance Range (Microhms)	DC Resistance Range (Ohms)	Applicable Military Specification	Degree of Space Experience	Anticipated Testing Require- ments	Sources
Coil (fixed) Radio Freq. Molded	.15 to 27	.030 to 2.75	MIL-C-15305	a	None	QPL-15305
	1.2 to 120	.075 to 4.10	MIL-C-15305	a	None	QPL-15303
	47 to 150	3.3 to 6.4	MIL-C-15305	a	None	Delevan Corp.
	180 to 390	5.5 to 8.7	MIL-C-15305	a	None	Delevan Corp.
	470 to 1000	9.0 to 14.5	MIL-C-15305	a	None	Delevan Corp.
	1500 to 10000	22 to 70	MIL-C-15305	a	None	Delevan Corp.
	.22 to 22	.027 to 1.99	MIL-C-15305	a	None	RCA-B & C Division, Tele-Coil Co.
	.15 to 22	.03 to 2.5	MIL-C-15305	a	None	Delevan Corp.
	.47 to 39	.06 to 2.0	MIL-C-15305	a	None	Delevan Corp.
	47 to 5000	5.9 to 65	MIL-C-15305	a	None	Delevan Corp.
	24 to 240	2.5 to 7.4	MIL-C-15305	a	None	Delevan Corp.
	270 to 1000	8.0 to 70.0	MIL-C-15305	a	None	Delevan Corp.

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TABLE IV.6-3
LIST OF PREFERRED PARTS, CONNECTORS

Type	AWG. Wire Accom. Range	Applicable Military Specification	Degree of Space Experience*	Anticipated Testing Require-ments	Sources
Miniature Cylindrical Cable & Rack	22 thru 16	MIL-C-26482	c	None	Bendix Corp.
Subminiature Rectangular Rack & Panel (non-magnetic)	22 thru 20	MIL-C-8384	a	None	Cinch Mfg. Co.; Cannon Electric Co.
RF, Coaxial (TNC)	RG-141A/U	-	a	None	Automatic Metal Products Co.
RF, Coaxial Miniature High Temp.	RG-188/U	MIL-C-22557	c	None	Sealectro Corp.; Micon Electronics Corp.
Tip Jack	Probe. 080"	-	c	None	Electronic Molding Corp.
Ferrule RF Cable grounding	range of coaxial cable size		a	None	Burndy Corp. Amp Inc.
Terminal Board, Screw Type, Barrier Type	Current rating range 5 amps to 50 amps	5 to 22	c		H. B. Jones Div. Cinch Mfg.; Kulka Electric Corp.

NOTE: No preconditioning is required for connectors.

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c. Space experience confirmed without failures; extent of use not ascertained.
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TABLE IV.6-4
LIST OF PREFERRED PARTS, DIODES (ALL SILICON TYPES)

Similar to Type	Part Description	Military Designation	* Degree of Space Experi-ence	Antici-pated Testing Require-ments	Sources
1N249	USA1N249B	MIL-S-19500/134 (Sig. C)	c	None	General Electric, RCA
1N250	USA1N250B	MIL-S-19500/134 (Sig. C)	c	None	General Electric, RCA
1N483	USN1N483B	MIL-S-19500/118A (Navy)	d	None	Cont. Devices; Texas Inst.
1N561	USN1N561	MIL-S-19500/167 (Navy)	c	None	Columbus Electric Corp.
1N645	JAN1N645	MIL-S-19500/240A	a	None	General Electric, Texas Inst.
1N649	JAN1N649	MIL-S-19500/240A	b	None	General Electric, Texas Inst.
1N697	USN1N697	MIL-S-19500/141 (Navy)	c	None	Western Electric Co.
1N746A thru 1N758A	USN1N746A thru USN1N758A	MIL-S-19500/127B (Navy)	c	None	Cont. Devices; Motorola
1N821	USN1N821	MIL-S-19500/159 (Navy)	b	None	Transition Corp.
1N823	USN1N823	MIL-S-19500/159 (Navy)	c	None	Transition Corp.
1N827	USN1N827	MIL-S-19500/159 (Navy)	b	None	Transition Corp.

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TABLE IV.6-4 (Continued)
LIST OF PREFERRED PARTS, DIODES (ALL SILICON TYPES)

Similar to Type	Part Description	Military Designation	* Degree of Space Experience	Anticipated Testing Requirements	Sources
1N914	JAN1N914	MIL-S-19500/116A	a	None	Cont. Devices; Fairchild General Electric; Texas Inst.
1N935B	USN1N935B	MIL-S-19500/156A (Navy)	b	None	Dickson Electronic Corp.
1N938B	USN1N938B	MIL-S-19500/156A (Navy)	c	None	Dickson Electronic Corp.
1N941B	USN1N941B	MIL-S-19500/157A (Navy)	c	None	Dickson Electronic Corp.
1N944B	USN1N944B	MIL-S-19500/157A (Navy)	b	None	Dickson Electronic Corp.
1N963B	USN1N963B	MIL-S-19500/157A (Navy)	c	None	Dickson Electronic Corp.
1N963B thru 1N991B	USN1N963B thru USN1N991B	MIL-S-19500/117B (Navy)	c		Dickson Electronic, Motorola
1N1147	USA1N1147	MIL-S-19500/254 (Sig. C)	c	None	North Amer. Elect.
1N149	USA1N1149	MIL-S-19500/254 (Sig. C)	c	None	North Amer. Elec.
1N498A	USA1N1198A	MIL-S-19500/206 (Sig. C)	c	None	General Electric, RCA

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TABLE IV.6-4 (Continued)
LIST OF PREFERRED PARTS, DIODES (ALL SILICON TYPES)

Similar to Type	Part Description	Military Designation	* Degree of Space Experi-ence	Antici-pated Testing Require-ments	Sources
1N498A	USA1N1198A	MIL-S-19500/206 (Sig. C)	c	None	General Electric, RCA
1N1202	JAN1N1202	MIL-S-19500/260	b	None	Westinghouse
1N1206	JAN1N1206	MIL-S-19500/260	b	None	Westinghouse
1N1482	USA1N1482	MIL-S-19500/147 (Sig. C)	c	None	Western Elect.
1N1483	USA1N1483	MIL-S-19500/147 (Sig. C)	a	None	Western Elect.
1N1731	USA1N1731	MIL-S-19500/142 (Sig. C)	b	None	Pacific Semiconductor
1N1733	USA1N1733	MIL-S-19500/142 (Sig. C)	b	None	Pacific Semiconductor
1N1734	USA1N1734	MIL-S-19500/142 (Sig. C)	b	None	Pacific Semiconductor
1N2970B thru 1N3014B	USA1N2970B thru USA1N3014B	MIL-S-19500/124B (EL)	b	None	Dickson; Hoffman; Motorola
1N3016B thru 1N3050B	USN1N3016B thru USN1N3050B	MIL-S-19500/115B (Navy)	b	None	Dickson; Hoffman; Motorola
1N3070	USN1N3070	MIL-S-19500/169A (Navy)	c	None	General Electric
1N3189	USN1N3189	MIL-S-19500/155A (Navy)	c	None	Motorola
1N3191	USN1N3191	MIL-S-19500/155A (Navy)	c	None	Motorola

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TABLE IV.6-4 (Continued)
LIST OF PREFERRED PARTS, DIODES (ALL SILICON TYPES)

Similar to Type	Part Description	Military Designation	* Degree of Space Experience	Anticipated Testing Requirements	Sources
1N3206	USA1N3206	MIL-S-19500/195 (Sig. C)	c	None	Micro Semicond.; Pacific Semicond.
1N3207	USA1N3207	MIL-S-19500/230 (EL)	c	None	Pacific Semicond.
1N3600	USN1N3600	MIL-S-19500/231A (Navy)	c	None	Fairchild
1N3821A thru 1N3828A	USN3821A thru USN3828A	MIL-S-19500/115B (Navy)	c	None	Dickson, Motorola

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TABLE IV.6-5

LIST OF PREFERRED PARTS, INDUCTORS (GENERAL TYPES ONLY)

Type	Applicable Military Specification	Degree of Space Experience	Anticipated Testing Requirements	Sources
Power	MIL-T-27	a	None	QPL-27
Miniature	MIL-T-27	a	None	United Transformer Company (See note 1)

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c. Space experience confirmed without failures; extent of use not ascertained.

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TABLE IV.6-6
LIST OF PREFERRED PARTS, RELAYS

Type	Contact Configuration	Contact Rating	Applicable Military Specification	Degree of Space Experience	Anticipated Testing Requirements	Sources
Magnetic Latching Micro-miniature	2PDT	2 amps	MIL-R-5757	a	None	General Electric Corp.
Magnetic Latching Sub-miniature	2PDT	10 amps	MIL-R-5757	a	None	Babcock Corp.
Power Sub-miniature	2PDT	10 amps	MIL-R-5757	c	None	Babcock Corp.
Dry Circuit Micro-miniature	2PDT	30 μ amps	MIL-R-5757	c	Qualification Level Testing for Environment	General Electric Corp.; Babcock Corp.; Filtors Corp.
Dry Circuit Sensitive Micro-miniature	2PDT	30 μ amps	MIL-R-5757	c	Qualification Level Testing for Environment	Electronic Specialty Co.
General Purpose	6PDT	2 amps	MIL-R-5757	c	None	Electro Tec. Corp.
General Purpose	2PDT	2 amps	MIL-R-5757	b	None	Filtors Corp.
Sensitive	2PDT	2 amps	MIL-R-5757	a	None	Electronic Specialty Co.

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TABLE IV.6-7

LIST OF PREFERRED PARTS, RESISTORS

Part Description	Applicable Military Specification	Designation	Degree of Space Experience	Anticipated Testing Requirements	Source(s)
Fixed Carbon Composition	MIL-R-11	RC06 RC07 RC20 RC32	a	None	Allen Bradley
Fixed Film General Purpose	MIL-R-22684	RL07 RL20 RL32	a	None	Corning Glass
Fixed Deposited Film, High Stability	MIL-R-10509	RN55D RN60D RN65D RN70D	a	None	Electra; Mepco; Corning Glass; Sprague
Fixed Metal Film, Low Temp. Coeff, High Stability	MIL-R-10509	RN55C RN60C RN65C RN70C	a	None	Electra; Weston-Mepco; Ward Leonard
Fixed Wire-wound, accurate	MIL-R-93	RB52CE RB54CE RB56CE	a	None	Sprague; Mepco
Fixed Wire-wound, Power	MIL-R-26	RW67V RW68V RW69V	a	None	Ohmite; Ward Leonard; Page Dale
Variable Wire-wound, Trimmer		RT10 RT11 RT12	b	None	Corning Glass
Variables Non-Wire-wound, Trimmer	MIL-R-22097	RJ11 RJ12	b	None	Bourns

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c. Space experience confirmed without failures; extent of use not ascertained.

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TABLE IV.6-8
LIST OF PREFERRED PARTS, TERMINALS (NO PRECONDITIONING IS REQUIRED)

Type	Description	Degree of Space Experience	Anticipated Testing Requirements	Source
Insulated knurled shank	Standoff, double turret.	a	None	Electronic Molding Corp.
	Standoff, double hollow turret	a	None	
	Feed through, double turret and pin	a	None	
	Feed through, single turret and pin	a	None	
	Feed through, single turret and single turret	a	None	
	Feed through, double turret and double turret	a	None	
	Standoff, hollow single turret	a	None	
	Standoff, pin terminal	a	None	
	Standoff, single terminal	a	None	
	Feed through, pin terminal and pin terminal	a	None	

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TABLE IV.6-9

LIST OF PREFERRED PARTS, TRANSFORMERS (GENERAL TYPES ONLY)

Type	Applicable Military Specification	Degree of Space Experience	Anticipated Testing Requirements	Sources
Miniature	MIL-T-27	a	None	United Transformer Co.
Pulse	MIL-T-27	c	None	United Transformer Co.

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TABLE IV.6-10

LIST OF PREFERRED PARTS, TRANSISTORS

Similar to Type	Configuration	Part Description	Degree of Space Experience	Anticipated Testing Requirements	Sources
2N491	Unijunction	MM/2N491B	c	None	General Electric
2N657	NPN	JAN2N657 MIL-S-19500/ 74CJAN	a	None	Fairchild General Electric Texas Inst.
2N706	NPN	JAN2N706 MIL-S-19500/ 120AJAN	b	None	Fairchild Texas Inst.
2N709	NPN	2N709	c	None	Fairchild
2N718A	NPN	2N718A	b	None	Fairchild Texas Inst. General Electric
2N720A	NPN	2N720A	c	None	Fairchild General Electric
2N722	PNP	2N722	b	None	Fairchild Texas Inst.
2N869	PNP	2N869	b	None	Fairchild
2N910	NPN	2N910	b	None	Fairchild General Electric
2N914	NPN	2N914	c	None	Fairchild General Electric
2N916	NPN	2N916	b	None	Fairchild General Electric
2N918	NPN	2N918	c	None	Fairchild General Electric
2N930	NPN	USA2N930 MIL-S-19500/ 253 (SIG. C)	c	None	Fairchild General Electric
2N956	NPN	2N956	c	None	Fairchild General Electric

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-10 (Continued)

LIST OF PREFERRED PARTS, TRANSISTORS

Similar to Type	Configuration	Part Description	Degree of Space Experience	Anticipated Testing Requirements	Sources
2N996	PNP	2N996	c	None	Fairchild
2N1016C	NPN	USN2N1016C MIL-S-19500/ 102(NAVY)	b	None	Westinghouse
2N1094*	PNP	USA2N1094 MIL-S-19500/ 161 (SIG. C)	c	None	Western Electric
2N1132	PNP	USN2N1132 MIL-S-19500/ 177A (NAVY)	a	None	Western Electric Texas Inst.
2N1358*	PNP	JAN2N1358 MIL-S-19500/ 122A (JAN)	b	None	Motorola
2N1482	NPN	USA2N1482 MIL-S-19500/ 207 (SIG. C)	c	None	RCA
2N1486	NPN	USA2N1486 MIL-S-19500/ 180 (SIG. C)	c	None	RCA
2N1490	NPN	USA2N1490 MIL-S-19500/ 208 (SIG. C)	c	None	RCA
2N1514	NPN	USA2N1514 MIL-S-19500/ 208 (SIG. C)	b	None	RCA
2N1613	NPN	USN2N1613 MIL-S-18599. 181 (NAVY)	a	None	Fairchild, General Electric, Texas Inst.
2N1645*	PNP	2N1645	c	None	Western Electric

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-10 (Continued)

LIST OF PREFERRED PARTS, TRANSISTORS

Similar to Type	Configuration	Part Description	Degree of Space Experience	Anticipated Testing Requirements	Sources
2N1675	NPN	2N1675	b	None	Western Electric
2N1711	NPN	USN2N174 MIL-S-19500/ 225A (NAVY)	c	None	Fairchild, General
2N1724	NPN	USA2N1724 MIL-S-19500/ 262	c	None	Texas Inst.
2N1841	NPN	2N1841	c	None	Western Electric
2N1893	NPN	USN2N1893 MIL-S-19500/ 182 (NAVY)	b	None	Fairchild, General Electric, Texas Inst.
2N1973	NPN	2N1973	b	None	Fairchild, General Electric
2N2016	NPN	USA2N2016 MIL-S-19500/ 248 (SIG. C)	c	None	RCA
2N2049	NPN	2N2049	c	None	Fairchild, General Electric
2N2192	NPN	2N2192	c	None	General Electric
2N2303	PNP	2N2303	c	None	Fairchild
2N2432	NPN	2N2432	c	None	Texas Inst.
2N2443	NPN	2N2443	c	None	Fairchild
2N2484	NPN	2N2484	c	None	Fairchild

NOTE: All germanium transistors are marked with an asterisk (*); all others are silicon.

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-11
LIST OF PREFERRED PARTS, HOOK-UP WIRE - TFE TEFLON INSULATION
(NO PRECONDITIONING REQUIRED)

MIL-W-16878 Designation (Approved Types)	AWG Size	Number of Strands	Degree of Space Experience	Anticipated Testing Requirements	Sources (1)
ET	24	1	a	None	American Super-temp. Wire Co.;
ET	24	7	a	None	Hitemp Wire Co.;
ET	22	1	a	None	Phila. Insul. Wire Co.;
ET	22	7	a	None	Revere Corp. of America;
ET	20	1	a	None	Surpremant Mfg. Co.;
ET	20	7	a	None	Tensolite Wire Co.;
E	24	1	a	None	Times Wire and Cable Co.;
E	24	7	a	None	Times Wire and Cable Co.;
E	22	1	a	None	Times Wire and Cable Co.;
E	22	7	a	None	Times Wire and Cable Co.;
E	20	1	a	None	Times Wire and Cable Co.;
E	20	7	a	None	Times Wire and Cable Co.;
E	18	1	a	None	Times Wire and Cable Co.;

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.
b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.
c. Space experience confirmed without failures; extent of use not ascertained.
d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-11 (Continued)
LIST OF PREFERRED PARTS, HOOK-UP WIRE - TFE TEFLON INSULATION
(NO PRECONDITIONING REQUIRED)

Mil-W-16878 Designation (Approved Types	AWG Size	Number of Strands	Degree of Space Experience	Anticipated Testing Requirements	Sources (1)
E	18	19	a	None	Times Wire and Cable Co.;
E	16	1	a	None	Times Wire and Cable Co.;
E	16	19	a	None	Times Wire and Cable Co.;
E	14	1	a	None	Times Wire and Cable Co.;
E	14	19	a	None	Times Wire and Cable Co.;
EE	24	7	a	None	Times Wire and Cable Co.;
EE	22	7	a	None	Times Wire and Cable Co.;
EE	20	7	a	None	Times Wire and Cable Co.;
EE	18	19	a	None	Times Wire and Cable Co.;
EE	16	19	a	None	Times Wire and Cable Co.;
EE	14	19	a	None	Times Wire and Cable Co.;

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.
b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.
c. Space experience confirmed without failures; extent of use not ascertained.
d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-11 (Continued)
LIST OF PREFERRED PARTS, HOOK-UP WIRE - TFE TEFLON INSULATION
(NO PRECONDITIONING REQUIRED)

MIL-W-16878 Designation (Approved Types)	AWG Size	Number of Strands	Degree of Space Experience	Anticipated Testing Requirements	Sources (1)
EE	12	37	a	None	Times Wire and Cable Co.;
EE	10	37	a	None	Times Wire and Cable Co.;

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage.
Available data state that the MC 81, when used in a similar manner, is an improved version.

2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-12
LIST OF PREFERRED PARTS, RF COAXIAL CABLE
(NO PRECONDITIONING IS REQUIRED)

Designation	Degree of Space Experience	Anticipated Testing Requirements	Preferred Sources
RG-303/U	c	Lunar environmental qualification testing	American Supertemp. Wires; Hitemp Wire Co.; Supremant Mfg. Co.; Tensolite Wire Co.; Times Wire and Cable Co.; Microdot Inc.; Phila. Insulated Wire Boston Insulated Wire
RG-316/U	C	Lunar environmental qualification testing	

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage. Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-13

LIST OF PREFERRED PARTS, SHIELDED AND JACKETED HOOK-UP WIRE, (TFE TEFLON INSULATED NO PRECONDITIONING IS REQUIRED)

MIL-W-16878 Insulated Conductor Designation	AWG Size	Degree of Space Experience	Anticipated Testing Requirements	Preferred Sources
E	24	b	None	American Supertemp Wire;
E	22	c	None	Hitemp Wires;
E	20	c	None	Phila. Insul. Wire;
E	18	c	None	Revere Corp.;
E	16	c	None	Supremant Mfg. Co.;
E	14	b	None	Tensolite Wire Co.;
EE	20	c	None	Times Wire & Cable Co.;
E	24	c	None	
E	22	c	None	
E	20	c	None	
E	16	c	None	

*EXPERIENCE LEGEND:

a. Over a dozen successful spacecraft systems confirmed with some individual spacecraft orbital periods of continued operation exceeding 1 year.

b. Two successful spacecraft systems confirmed with a total cumulative operating time on both of 1.5 years with both systems still operating.

c. Space experience confirmed without failures; extent of use not ascertained.

d. Eight successful spacecraft systems confirmed with one of these having over 1 year of operation.

NOTES:

1. The predecessor to this unit, the MC 80, has had significant space usage.
   Available data state that the MC 81, when used in a similar manner, is an improved version.
2. Preconditioning requirements will be included in the procurement document.

TABLE IV.6-14

LIST OF PREFERRED MATERIALS, ADHESIVES

Type	Source
Resin Type	
FM1000 (.025 lbs per sq. ft.)	Bloomingdale Rubber Co.
Pro-Seal 501	Coast Pro Seal & Mfg. Co.
Ecco Bond 45 with Catalyst 15	Emerson & Cuming Co.
EC 1386	Minnesota Mining & Mfg. Co.
EC 1838 A and B	Minnesota Mining & Mfg. Co.
Silastic 140	Dow Corning Corp.

TABLE IV.6-15

LIST OF PREFERRED MATERIALS, CHEMICALS

Type	Source
<u>Acids</u>	
Acetic Glacial	J. T. Baker Chemical Co.
Hydrochloric, Comm. 19.8 Baume	J. T. Baker Chemical Co.
Nitric, Tech. 41.5 Baume	J. T. Baker Chemical Co.
Sulfuric, Comm. 66 Baume	J. T. Baker Chemical Co.
<u>Salts</u>	
Sodium Dichromate ($Na_2Cr_2O_7 + 2H_2O$)	J. T. Baker Chemical Co.
<u>Fillers</u>	
Alumina T-61 Tabular (325 Mesh)	Aluminum Co. of America
Aluminum, Powder (Grade 101)	Metal Disintegrating Co.
Cab-O-Sil (uncompressed)	Godfrey Cabot Co.

TABLE IV.6-15 (Continued)

LIST OF PREFERRED MATERIALS, CHEMICALS

Type	Source
<u>Solvents</u>	
Acetone	J. T. Baker Chemical Co.
Alcohol, Isopropyl	Union Carbide - Carbon Co.
Chlorothene	Dow Chemical Co.
Methyl Ethyl Ketone	J. T. Baker Chemical Co.
Methylene Chloride	E. I. duPont
Toluene	J. T. Baker Chemical Co.
V M & P Naphtha	J. T. Baker Chemical Co.
<u>Thinners</u>	
TL-29	Finch Paint & Chemical Co.
TL-51	Finch Paint & Chemical Co.
Thinner (FS-1985090)	Egyptian Lacquer Mfg. Co.
Water	
Distilled Water	

TABLE IV.6-16

LIST OF PREFERRED MATERIALS, COATINGS, ORGANIC

Type	Source
<u>Black</u>:	
Semi-Gloss (FS-1985090)	Egyptian Lacquer Mfg. Co. or Maas and Weldstein
Flat, Cat-a-lac (463-3-8) (FS-1985999)	Finch Paint & Chemical Co.
Flat, Yarnall (FS-1985983)	Yarnall Paint Co.

TABLE IV.6-16 (Continued)

LIST OF PREFERRED MATERIALS, COATINGS, ORGANIC

Type	Source
Black: (Continued)	
Gloss, Solfo (MIL-E-5557HR)	Solfo Paint Mfg. Co.
Gloss, (Tile-Cote 1202 A and B)	Wilbur and Williams Co.
Clear:	
Resiweld 200 A and 200 B	H. B. Fuller Co.
PC 12-007 A and B	Hysol Corp.
SMP-62 and 63	Western States Lacquer Co.
Strippable:	
Lotal LX 497	Naugatauck Chemical Co.
Teflon:	
Ermalon 310	Acheson Industries
White:	
Flat, PV-100	Vita-Var
Gloss, Tile-Cote 1201 A and B	Wilbur & Williams Co.

TABLE IV.6-17

LIST OF PREFERRED MATERIALS, COMPOUNDS

Type	Source
Release Agents:	
MS 122	Emerson & Cuming
Silicone Release Agents:	
DC-7	Dow Corning Corp.
Putty, SS-90	General Electric Co.

TABLE IV.6-17 (Continued)

LIST OF PREFERRED MATERIALS, COMPOUNDS

Type	Source
Resins — Casting:	
J-1158	Armstrong Cork Co.
Corfil 615	Bloomingdale Rubber Co.
Araldite 502	Ciba Products Co.
Adiprene L-100	E. I. duPont
Eccobond 55	Emerson & Cuming Co.
Stycast 1090	Emerson & Cuming Co.
Stycast 1095	Emerson & Cuming Co.
Stycast 2651	Emerson & Cuming Co.
Stycast 2651MM	Emerson & Cuming Co.
Hysol 4102	Hysol Corp.
Hysol 4175	Hysol Corp.
Hysol 4238 (6250)	Hysol Corp.
M648	Rubber & Asbestos Corp.
M688	Rubber & Asbestos Corp.
PR 1527 Amber	Products Research Company
PR 1527 Black	Products Research Company
Epon 815	Shell Chemical Corp.
Epon 828	Shell Chemical Corp.
Solithane 113 (8977866-1)	Thiokol Chemical Corp.
Solithane 113-C-300 Curing Agent	Thiokol Chemical Corp.
Resins — Foaming:	
Eccofoam FP	Emerson & Cuming Co.

TABLE IV.6-17 (Continued)

LIST OF PREFERRED MATERIALS, COMPOUNDS

Type	Source
Silicones:	
LTV-602	General Electric Co.
RTV-11	General Electric Co.
RTV-40	General Electric Co.
RTV-60	General Electric Co.
Silastic S-5313	Dow Corning Co.
Silastic S-5314	Dow Corning Co.
Sealers:	
Albaseal	Johns-Manville Co.
PRC-1201Q	Products Research Corp.
Curing Agents:	
E-8	Armstrong Cork Co.
BR-801	Bloomingdale Rubber Co.
HN-951	Ciba Products Corp.
MOCA	E. I. duPont
Catalyst 9	Emerson & Cuming Co.
Catalyst 11	Emerson & Cuming Co.
Catalyst FP 12-6	Emerson & Cuming Co.
SCR-05	General Electric Co.
Hysol 3418	Hysol Corp.
Hysol 3475	Hysol Corp.
T-9	Metal & Thermit Co.
T-12	Metal & Thermit Co.
CH-8	Rubber & Asbestos Corp.
CH-16	Rubber & Asbestos Corp.

TABLE IV.6-17 (Continued)

LIST OF PREFERRED MATERIALS, COMPOUNDS

Type	Source
Curing Agents: (Continued)	
CH-38	Rubber & Asbestos Corp.
Diethylenetriamine	Shell Chemical Co.
Diethylenetriamine	Union Carbide Chemical Co.
Triethylenetetramine	Union Carbide Chemical Co.
Inks – Marking:	
Yellow, Resiweld 227	H. B. Fuller Corp.
Primers:	
Cat-A-Lac, Green 463-2-2	Finch Paint & Chemical Co.
A-4094	Dow Corning Co.
SS-4004	General Electric Co.
PR-1531	Products Research Co.

D. BASIS FOR SELECTION

1. Silicon

Silicon devices were selected over germanium because of the higher junction temperature capability and lower leakage current. In a few cases germanium devices were selected only when functionally not covered by a suitable silicon device.

Junction temperature derating is the most valuable semiconductor derating method. Hence, the use of silicon transistors, semiconductor diodes, and circuits well below their temperature ratings will result in far better reliability than the use of a germanium unit near its rating. Also, silicon provides exceptionally low leakage at room temperature and operates satisfactorily at elevated temperatures. The use of germanium would require both extreme junction temperature and extreme leakage current derating to approach the space application required. Such extreme derating, would greatly restrict the device functional use in a circuit. This concentration on silicon would eliminate the use of about 50 percent of the devices listed in MIL-STD-701C. To provide the reliability required at a reasonable confidence level the power derating factor (stress ratio) will be in the order of 0.4 and less.

2. **Transistor Cases**

For convertional parts, the TO-18 and TO-5 were selected because these are the most proven standard package available to provide the small size and low weight for space application. The TO-18 is preferred over the TO-5 for weight and size consideration. The TO-5 which has higher power rating than the TO-18, 800 mW compared to 500 mW, is provided to permit suitable derating to obtain the required reliability where the TO-18 device may be marginal.

For power devices the double ended stud type package, as used for the 2N1724 transistor, has been selected as the most desirable. This type stud package provides for ease of mounting, lead connection, and heat dissipation. However, power units having other than the double ended stud package were selected because of availability and proven past performance.

3. **Silicon Planar Structure**

The silicon planar devices without organic surface coatings or case fillers was a prime consideration for selection. This type has evolved to be the most reliable transistor structure available today. This structure provides for clean surface junctions, sealed vacuum-tight at high temperature in the absence of water vapor, including the very important one of a surface oxide on silicon. This passivated oxide surface eliminates the need for organic surface coatings and case fillers that are susceptible to radiation damage and unknown degradation.

Hence, some of the mesa and allow junction types listed in MIL-STD-701C have not been selected if superseded by a more reliable silicon planar device.

4. **Frequency**

Since the planar diffusion technique inherently provides for higher frequency (> 20 Mc) devices and in turn higher beta, the selection was guided towards these. These would also cover lower frequency applications and provide the higher frequency types which have better radiation damage resistance.

5. **Integrated Modules**

Where applicable, integrated modules have also been selected for use in the Command and Control and Telemetry Subsystems. Their use permits a substantial power, size, and weight reduction and also consideration of redundancy as a means for enhancing the system's reliability. These have been used in several spacecraft with success and are also proposed here.

6. **Other Parts**

Other parts selected have a proven use in space and it is anticipated that their use will present no additional problems or hazards if used within the restraints imposed by the environment.

7. **Materials**

Some materials have been selected. However, because of limited space experience and where environmental extremes impose conditions beyond the level of present space experience, additional testing will be needed for certification of the materials proposed.